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Journal
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Vol. 233 JUNE, 1942 No. 6

BENJAMIN FRANKLIN—"PHILOSOPHICAL REVOLUTIONIST." *

BY

BERNHARD KNOLLENBERG,

Librarian, Yale University, New Haven, Connecticut.

I am so much interested in Franklin that I accepted your invitation to speak in this series of Franklin Memorial Lectures without first inquiring as to my topic. I was later pleasantly surprised to learn that it was to be "Franklin as a Philosophical Revolutionist." This is a side of his character which is especially interesting to me and which has never been fully developed, though there are many sidelights on it in Mr. Van Doren's fine book.

Until the latter work appeared, the most careful study of Franklin's life was William Cabell Bruce's "Benjamin Franklin Self Revealed." Yet even Bruce profoudly misread Franklin's character in declaring that "By nature and training Franklin was profoundly conservative at the core." This means, I take it, that Bruce considered Franklin a person who tended to accept and adhere to the existing order of things, whereas, Franklin was in fact the very opposite of this. For from the beginning to the end of his life, we find him approaching every canon of thought or conduct with the

* Delivered in the Hall of The Franklin Institute, November 3, 1939. This was one of the papers in the "Meet Dr. Franklin" Conference.

(Note—The Franklin Institute is not responsible for the statements and opinions advanced by contributors in the JOURNAL.)

question, "Is this logical? Does it hold water? Shall I be bound by it?"—no matter how old and generally accepted the idea, tradition or rule might be. True, he was cautious; he was shrewd; he was temperate. This, however, shows, I think, not that he was conservative but that he was wise; that he challenged the *status quo* with the approach of the philosopher; that, in short, he was a *philosophical* revolutionist.

My grounds for this view are numerous and diverse. To begin with, one of the relatively few things we know about Franklin's youth is that he early challenged the established religious teachings of his day. His first serious difficulty, when a boy of only fifteen in Boston, arose out of his articles in his brother's newspaper and some challenging remarks in conversation about religious matters. True, his brother's harshness to the young printing apprentice may have been a factor, but, to judge from the "Autobiography," the decisive reason for Franklin's taking French leave from his apprenticeship was that things were getting a little hot for him among those resentful of his rebellious, revolutionary attitude toward the religious tenets of the community.

Again, when he gets to Pennsylvania, we find evidence not only of the industry, economy, shrewdness in business we read and hear so much about, but also of his challenge to the established system of government in Pennsylvania. The wealthy and powerful Penn family, the proprietors of the province, their governor and satellites, were in a position to be most helpful to the ambitious Franklin by throwing printing business his way. But they were insisting that their relation to the colony was the same as that of the King to the royal colonies; that it would be as logically and legally indefensible for the legislature in Pennsylvania to tax the lands owned by the proprietors as for the legislatures in the royal colonies to tax the lands owned by the Crown. Franklin, approaching this question with his challenging mind, said: Why should these proprietors be exempt from taxation? As the community is developed, as peasants and yeomen come here from abroad and improve their lands, they are going to increase the value of these proprietors' lands. Why should the proprietors receive that increase in value, while paying nothing in the meantime towards maintaining the community

that is enriching them? The revolutionist, Henry George, you will recall, stressed that idea many years later.

I do not contend that Franklin was unique in holding this view. It is one of those ideas that might strike any intelligent mind at any time. But I think it was original in the sense that it was Franklin's own insight and reasoning that led him to take this, at that time, revolutionary stand.

Franklin's approach to science was another illustration of his revolutionist tendencies. The outstanding scientists have, of course, all had challenging minds—have all, in a sense, been revolutionists in their respective fields. But many able and useful scientists are not revolutionists. They may be teachers or conductors of research along previously well-defined lines. Most of them would not, if they had lived in Franklin's time and place, have risked playing with the sacrilegious idea that lightning—that threat of divine punishment for the wicked, more immediately visible than hell fire—was really but a manifestation of the "electric fluid" which the experimentally-minded were having so much fun collecting in Leyden jars. But Franklin, with the boldness, the openness of mind, the determination to try to find and act on the truth, irrespective of tradition, that marks the revolutionist, made his great discovery that lightning was but a large-scale electrical discharge.

Though I am later going to give further grounds for my thesis that Franklin was a thorough-going revolutionist, I shall stop for a moment to contrast Franklin with some others who were of a somewhat different calibre, and point out the essential difference between their revolutionism and Franklin's.

As you think back over the famous revolutionists who have cropped up in history, you will recall that most of them were highly pugnacious persons. This is, I think, one reason that so many of them have been, or started out to be, lawyers; the same instinct for the argumentative that made the lawyers' profession attractive led them to challenge certain of the established tenets held by those around them. Such men are likely to be revolutionists in but a single chosen field, while remaining otherwise conservative. Furthermore, even within the special field in which they became celebrated they are likely to revert to conservatism. Luther, perhaps

the most noted of these in the field of religion, is an example of this familiar type. Highly pugnacious and, in most respects, a hide-bound conservative, he eventually became extremely dogmatic and inflexible even in the field of religion. Incidentally, Luther, as you probably recall, started out to be a lawyer. Another of the same kind was Patrick Henry. Having had his day as a political revolutionist, he eventually became one of the conservative leaders of Virginia.

Another group of revolutionists are those who, having suffered injury at the hands of the existing political or economic order, strike out against it in the frenzy of their anguish or in the desire for revenge. Thomas Paine, and most of the Russian revolutionists seem to have been of this type. This fact may account for the iron-bound rule into which, after Lenin's death, the Russian Revolution appears to have developed.

Franklin does not belong in either of these categories. He had no bitter scores to pay off, and, far from his revolutionism being but a passing phase, we find him a consistent challenger throughout life. The question: Is the existing way the sound way, never ceased to ring in his ears.

Take the part in which he made his most enduring contribution: his part in the American Revolution. Franklin was not like Washington, a tobacco planter, exploited and knowing that he was exploited by the British law requiring his tobacco to be sent exclusively to Britain, thereby restricting his market and reducing his profits. He was not a large owner of slaves, one of whose essential elements of food—salt—and most of whose clothing—the rough Osnaburg cloth—coming from the continent of Europe, must be imported through Great Britain so that the British merchant could take his toll. (I do not mean to imply by this comparison that economic motives alone swayed Washington, but his letters show how important a part they played in forming his views.) Franklin was a clear gainer from his connection with the British Empire.

He held a lucrative jo[illegible] the British Colonial Post Office Department. His newspapers flourished in part as a result of his connections with the British Government. His son, William, was appointed by the King to the governorship of

New Jersey. When Franklin looked at the British government from the standpoint of gain or loss to himself, he must have realized that he was a beneficiary, not a victim, of the connection. Yet when the question of British taxation began acutely to present itself, we find his revolutionary character, his inevitable challenge to the existing, but logically indefensible order, slowly but surely unfolding.

In his first published statement on the matter in 1766, at the time the repeal of the Stamp Act was under consideration, Franklin said in his famous hearing before the House of Commons:

> I never heard any objection to the right of laying duties to regulate commerce; but a right to lay internal taxes was never supposed to be in Parliament, as we are not represented there.

Although he may conceivably have been concealing his feelings, I think it fair to assume that this was Franklin's honest approach to the question.

Later, after thinking the matter over more carefully, we find him writing on March 13, 1768, to his son William,

> The more I have thought and read on the subject the more I find myself confirmed in the opinion that no middle doctrine can be well maintained, I mean not clearly with intelligible arguments. Something might be made of either of the extremes; that Parliament has a power to make *all laws* for us or that it has a power to make *no laws* for us; and I think the argument for the latter more numerous and weighty, than those for the former.

Two years later we find a further development. At that time, in writing to an old friend—Samuel Cooper—Franklin is no longer balancing things this way and that. He says flatly

> I could wish that such Expressions as the Supreme Authority of Parliament . . . were no longer seen in our publick Pieces. They . . . tend to confirm a Claim of Subjects in one Part of the King's Dominions to be Sovereign over their Fellow Subjects in another Part of his Dominions, when in truth they have no such Right, and their Claim is founded only in Usurpation.

He concedes that the King has certain rights as the source of the colonial charters, but maintains that Parliament as a law-making body had no power whatsoever over the colonies.

From this it was an easy transition to the view, expressed in a letter to Thomas Cushing, Speaker of the House of

Representatives in Massachusetts, July 1773, in which, for the first time, Franklin puts himself squarely on record in favor of a program smacking strongly of treason. He writes Cushing that the Colonies

> should engage firmly with each other that they will never grant Aids to the Crown in any General War, till those rights are recognized by the King and both Houses of Parliament; communicating at the same time to the Crown this their Resolution.

The next step was, of course, the final one of open rebellion, when in 1776, as might be expected, we find Franklin among the five members of Congress who drafted the Declaration of Independence.

Unlike some of the other prominent signers, however, there was, in Franklin's case, no relapse into conservatism. Death alone put an end to his challenging mind and the readiness to follow wherever the challenge might lead him. In November 1789, when Pennsylvania was going through the throes of a great constitutional crisis, the question arose whether a second house should be added to the Pennsylvania Legislature, to represent, not the people as a whole, but the wealth of the State. The wealthy—and Franklin was at the time one of the wealthy men of the State—were thus in effect to have a veto power over the legislation passed by the "mobility." But Franklin strongly opposed the bill, and, replying to an article in the Federal Gazette of November 3, 1789, wrote in a memorandum headed "Queries and Remarks":

> And why is property to be represented at all? The accumulation of property and its security to individuals in every society must be in effect the protection afforded it by the joint strength of the society in the execution of its laws. Private property, therefore, is a creature of society and is subject to the call of that society whenever its necessities shall require, even to its last farthing.

This is a doctrine not far from Karl Marx's "from each according to his abilities, to each according to his needs" of a half century later; a doctrine which Lenin and some other well-known revolutionists have put into action in our present century.

To come back then to the statement of Bruce, I think that he must have been making the common error of using the term "conservative" as the equivalent of cautious,

temperate. philosophic, wise. Franklin was all of these, but, far from being "at the core," a conservative, he was a revolutionist of extraordinary consistency.

I will take a few moments more of your time to say a word, as I was asked to do, about our Mason-Franklin Collection at the Yale University Library. Most of you know something about this collection. But it is not generally known that of the unpublished Franklin letters in the collection, two of the finest were written to distinguished Pennsylvania colonials. The first is to Joseph Galloway, Franklin's closest American friend in middle life, who, unable to follow him in his career of political revolution, went to England as one of the loyalists. The second is to the Quaker, Isaac Norris, for may years Speaker of the Assembly in colonial Pennsylvania.

I hope Philadelphians will some day give a little more recognition to these two men, especially Galloway. Perhaps a visit to the Mason-Franklin Collection at Yale will move one of you to write a life of this man, so far more worthy of a biography than most of the people about whom books are written these days. I should enjoy showing you this Collection, for your presence and close attention indicate that you share my deep interest in your greatest citizen, the philosophical revolutionist, Benjamin Franklin.

On Riding Hummingbirds.—(Industrial Bulletin of Arthur D. Little, Inc., No. 176.) Helicopter growth and development may parallel that of the automobile. Lack of landing space is now a major handicap to private flying, but the helicopter lands on an area fifty to eighty feet square, with almost any surface condition, and with greater safety through being able to land with no forward speed at all. The first successful helicopter, built in 1936 in Germany by Foche-Achgelis Company, stimulated the interest of such other designers as Louis Brequet in France, Laurence Le Page of Day and Zimmermann, Inc., and Igor Sikorsky of the Vought-Sikorsky Aircraft Division of the United Aircraft Corporation and designer of the Pan-American "clippers." The most successful helicopter developments announced in this country have been those of Mr. Sikorsky. The present Sikorsky helicopter weighs 1290 pounds, ascends and descends vertically, hovers over a spot near the ground, wind or no wind, flies backwards, forwards or sidewise, or rotates about its axis. It is also reported to go seventy to eighty miles per hour, operate with little noise, handle as simply as an airplane, and alight on land or water with the same landing controls. Presumably this helicopter can also duplicate performances of Foche's design, which rose to 11,700 feet and was tested for safe landing without power although similar tests have not been made with Sikorsky's "experimental model" helicopter. The helicopter differs from the autogiro in having power applied directly to its rotating wing in flight. Helicopters are not made with a front, direct-drive propeller, as in the autogiro, and a top, direct-drive rotating wing, because power developed by such a propeller would be absorbed largely by the rotating wing. Fundamental helicopter design problems are said to be solved, with problems of vibration and control still to be met. Helicopters may compete more directly with automobiles than with airplanes. Airplane trends are toward greater speeds, greater cruising distances, and hence larger required landing and take off space. The helicopter is a machine of low speed and short cruising range of perhaps 200 to 300 miles.

R. H. O.

CHARACTER TABLES FOR TWO SPACE GROUPS.

BY

CONYERS HERRING, PH.D.,

Princeton University.

In certain problems in the physics of crystals it is useful to know the irreducible representations of the space group with which one is working.[1] The construction of character tables for these irreducible representations is rather easy for space groups in which each lattice point possesses the full symmetry of the point group:[2] the method is illustrated in reference 1 where character tables are given for the space groups $\mathfrak{O}_h^1$, $\mathfrak{O}_h^9$, and $\mathfrak{O}_h^5$ (simple, body centered, and face centered cubic lattices). For space groups in which no point of space possesses the symmetry of the point group, the construction of character tables is more laborious, and so publication of tables for such groups may be of value. Tables are given in this paper for the two most important space groups of this type, $\mathfrak{D}_{6h}^4$ (close-packed hexagonal) and $\mathfrak{O}_h^7$ (diamond type).

NOTATION AND GENERAL THEORY.

To designate particular operations of a space group the following notation, introduced by Seitz,[2,3] will be used. Let x_i ($i = 1$ to 3) be the coördinates of a point of space, referred to some rectangular coördinate system. An operation of a space group which takes any point x_i into $x'_i = \sum_j a_{ij}x_j + a_i$ will be designated by the symbol $\{\alpha|\boldsymbol{a}\}$, or alternatively simply by $\mathfrak{A}$. Here α stands for the square matrix $\|a_{ij}\|$,

[1] The role played by the irreducible representations of space groups in the electron theory of metals has been discussed by Bouckaert, Smoluchowski, and Wigner, *Phys. Rev.*, **50**, 58 (1936). A similar application occurs in the theory of the normal vibrations of a crystal lattice.

[2] A general theory of the irreducible representations of space groups has been given by F. Seitz, *Annals of Math.*, **37**, 17 (1936).

[3] F. Seitz, *Zeits. f. Kristallographie* (A) **88**, 433 (1934), **90**, 289 (1935), **91**, 336 (1935), **94**, 100 (1936).

and thus describes a proper or improper rigid rotation about the origin; similarly $\boldsymbol{a}$ is a one-column matrix, or vector, defining a rigid translation. If $\mathfrak{C} = \mathfrak{AB}$ is the product of two such operations we have

$$\{\gamma|\boldsymbol{c}\} = \{\alpha|\boldsymbol{a}\}\{\beta|\boldsymbol{b}\} = \{\alpha\beta|\alpha\boldsymbol{b} + \boldsymbol{a}\},$$

where the products $\alpha\beta$ and $\alpha\boldsymbol{b}$ are to be interpreted according to the usual rules of matrix multiplication. Thus the vector $\boldsymbol{c}$ is obtained by applying the rotation α to $\boldsymbol{b}$ and adding $\boldsymbol{a}$:

$$c_i = \sum_j a_{ij}b_j + a_i.$$

The elements of the translation group are of the form $\{\varepsilon|\boldsymbol{t}\}$ where ε is the unit matrix and $\boldsymbol{t}$ is a vector of the form $n_1\boldsymbol{t} + n_2\boldsymbol{t}_2 + n_3\boldsymbol{t}_3$, the n's being integers and $\boldsymbol{t}_1$, $\boldsymbol{t}_2$, $\boldsymbol{t}_3$ being the three "fundamental translations."

To explain the meaning of the tables and the methods used in obtaining them, it will be necessary first to recall a few facts established by Seitz.[2] Any irreducible representation of a space group can be referred to a basis reducing the translation group, which is Abelian: in other words, we may specify that the matrices representing all the elements of the translation group be of diagonal form. In any irreducible representation of the translation group each translation $\{\varepsilon|\boldsymbol{t}\}$ is represented by a complex number $e^{-i\boldsymbol{k}\cdot\boldsymbol{t}}$, where $\boldsymbol{k}$ is independent of $\boldsymbol{t}$ and may be called the "wave vector" of the representation. The wave vector of a given representation is uniquely determined only to within a vector $\mathbf{K}$ whose scalar product with any $\boldsymbol{t}$ is a multiple of 2π, i.e., only to within 2π times an arbitrary vector of the reciprocal lattice. We shall therefore speak of two wave vectors as being "equivalent" if their difference is 2π times a reciprocal lattice vector; it will suffice to confine our attention only to those wave vectors whose length is less than or equal to the length of any other equivalent vectors.[4] These wave vectors terminate in the interior and on the surface of a polyhedron called the first Brillouin zone; [5] the boundary planes of this

[4] These are the so-called "reduced wave vectors." Cf. reference 1, p. 62; A. Sommerfeld and H. Bethe, "Handbuch der Physik," 24/2, 394.

[5] See Sommerfeld and Bethe, reference 4, p. 385.

polyhedron are the perpendicular bisectors of the vectors **K** mentioned above.

Let ψ_k be an element of the representation space which has wave vector $\boldsymbol{k}$. The set of all operations of the space group which take any such ψ_k into an element with the same wave vector $\boldsymbol{k}$ (or an equivalent one) is a subgroup of the space group, and may be called the group G^k of the wave vector $\boldsymbol{k}$.[6] If σ^k is a subspace of the representation space which has wave vector $\boldsymbol{k}$ and which is transformed irreducibly by G^k, it can be shown that σ^k and all the other subspaces into which it is transformed by operations of the complete space group span a subspace which is irreducible under the complete group. Therefore the problem of reducing the space group is equivalent to the problem of finding, for each wave vector $\boldsymbol{k}$, all the irreducible representations of G^k which have wave vector $\boldsymbol{k}$. Let us consider such a representation. If there happens to be an element $\mathfrak{T} = \{\mathfrak{e}|\boldsymbol{t}\}$ of the translation group such that $\boldsymbol{k}\cdot\boldsymbol{t}$ is an integer times 2π, then, for any $\mathfrak{A}$ in G^k, $\mathfrak{T}\mathfrak{A}$ will be represented by the same matrix as $\mathfrak{A}$. In computing the characters of such representations of G^k we may therefore proceed as if each such $\mathfrak{T}$ were the identity; in other words, we need compute only the characters of the corresponding representations of the factor group G^k/T^k, where T^k is the group of all translations $\mathfrak{T}$ for which $\boldsymbol{k}\cdot\boldsymbol{t}$ is a multiple of 2π.

When $\boldsymbol{k} = 0$, T^k is the whole translation group, and G^k/T^k is the point group of the space group. As the characters of all the crystallographic point groups are known,[7] it is not necessary to discuss here representations with wave vector 0. When $\boldsymbol{k}$ is a "general" vector ending inside the Brillouin zone, G^k consists only of the translation group, and the construction of its representation is trivial. When $\boldsymbol{k}$ ends inside the Brillouin zone, but lies inside the direction of an axis of symmetry or in a plane of symmetry, G^k contains

[6] G^k contains all operations $\{\alpha|\mathbf{a}\}$ whose point operations α leave the vector $\boldsymbol{k}$ unchanged, or take it into a new vector which differs from $\boldsymbol{k}$ by 2π times a reciprocal lattice translation.

[7] Characters for the more important point groups have been given by H. Bethe, *Ann. d. Phys.*, **3**, 133 (1929); those for all point groups have been given by E. Wigner, *Gott. Nachr.* (1930), p. 133.

in addition the operation of rotation about the axis, or of reflection in the plane (sometimes both). For such $\boldsymbol{k}$ vectors the desired characters of G^k can easily be obtained by using the fact that for $0 < \lambda \leq 1$, $G^{\lambda k}$ is the same as G^k. For consider any element $\mathfrak{A} = \{\alpha|\boldsymbol{a}\}$ of G^k. If m is an integer such that $\alpha^m = \varepsilon$, the translation operation $\mathfrak{A}^m = \{\varepsilon|\boldsymbol{t}\}$ will be represented by $e^{-i\boldsymbol{k}\cdot\boldsymbol{t}}$ times the unit matrix in any representation with wave vector $\boldsymbol{k}$. Therefore the eigenvalues of $\mathfrak{A}$ occurring in this representation will be found among the various m-th roots of $e^{-i\boldsymbol{k}\cdot\boldsymbol{t}}$. Which ones of these roots occur can be determined by considering the sequence of wave vectors $\lambda\boldsymbol{k}$ as $\lambda \to 0$: the eigenvalues of each $\mathfrak{A}$ must as $\lambda \to 0$ approach the eigenvalues of the corresponding α in a representation of the point group of G^k. Thus the only $\boldsymbol{k}$ vectors for which the construction of character tables can be non-trivial are vectors terminating on the boundary of the Brillouin zone.

Character tables are given below for the groups G^k/T^k for all "points of symmetry" on the boundary of the Brillouin zone. By a "point of symmetry" is meant a wave vector $\boldsymbol{k}$ whose G^k contains more elements than the $G^{k'}$ of any neighboring vector $\boldsymbol{k}'$. To facilitate construction of characters for wave vectors $\boldsymbol{k}'$ terminating on "lines of symmetry" lying in the boundary of the Brillouin zone, character tables are also given for the representations with wave vector $\boldsymbol{k}$ of the groups $G^{k'}/T^k$, for each of the points of symmetry $\boldsymbol{k}$ which lie on the line of symmetry in question. Here a "line of symmetry" is a line such that all wave vectors $\boldsymbol{k}'$ terminating on it (with the exception of certain isolated points $\boldsymbol{k}$ of higher symmetry) have the same group G^k, which contains more elements than the $G^{k''}$ of any $\boldsymbol{k}''$ near the line but not on it. These tables thus give the limits approached by the characters of $G^{k'}$ as $\boldsymbol{k}' \to \boldsymbol{k}$, and these limiting values determine easily the characters at any point $\boldsymbol{k}'$ on the line, by the same reasoning which was outlined above for lines of symmetry lying inside the Brillouin zone. Finally, for points on the boundary of the Brillouin zone not lying on lines of symmetry, G^k can contain at most a reflection or glide reflection in addition to the translation group, hence there can be at most two irreducible representations with a given wave

vector. These, being one-dimensional, can be constructed by inspection.

A brief description will now be given of the methods used in obtaining character tables for the groups G^k/T^k. The fact that $\boldsymbol{k}$ is a point of symmetry in all the cases to be considered has the consequence that each G^k/T^k or $G^{k'}/T^k$ is a group of finite order. Now it is known [8] that the characters of any finite group can be deduced algebraically from the coefficients c_{ijl} which express how many times each class C_l of conjugate group elements occurs in the product of classes C_i and C_j:

$$C_iC_j = \sum_l c_{ijl}C_l.$$

If h_i is the number of elements in class C_i, the equations determining the characters are [8,9]

$$\frac{h_i\chi_i{}^d}{\chi_E{}^d} \cdot \frac{h_j\chi_j{}^d}{\chi_E{}^d} = \sum_l c_{ijl} \frac{h_l\chi_l{}^d}{\chi_E{}^d}. \tag{1}$$

Each set of solutions of these equations gives the characters $\chi_i{}^d$ of the various classes i in some representation d, in terms of the character of the identity E, which is the dimensionality of d. This last can then be determined from the condition [9]

$$\sum_i h_i|\chi_i{}^d|^2 = \text{order of group}. \tag{2}$$

For the groups G^k/T^k, $G^{k'}/T^k$ which are considered below, the solution of equations (1) is greatly simplified by noting at the outset that when d is a representation with wave vector $\boldsymbol{k}$ many of the characters vanish and others are proportional to one another. For if $C_tC_i = C_j$, where C_t is the class consisting of the coset $\{\mathfrak{e}|\boldsymbol{t}\}T^k$, then $\chi_j{}^d = e^{-i\boldsymbol{k}\cdot\boldsymbol{t}}\chi_i{}^d$ if d has wave vector $\boldsymbol{k}$; and now if $i = j$, $\chi_j{}^d$ must vanish unless C_t is the identity class. In a number of cases solution of equations (1) was unnecessary, as it turned out that G^k/T^k on $G^{k'}/T^k$ was Abelian, or was the direct product of a point group with an Abelian group.

[8] W. Burnside, *Proc. Lond. Math. Soc.*, **33**, 146 (1900).

[9] A. Speiser, "Theorie der Gruppen von Endlicher Ordnung" (2 ed. Berlin 1927), p. 174.

SPACE GROUP $\mathfrak{D}^4_{6h}$ (CLOSE-PACKED HEXAGONAL).

The translation group is generated by two fundamental translations t_2, t_3, of equal length and in directions 120° apart, and a third, t_1, of arbitrary length and in a direction perpendicular to the plane of t_2 and t_3. Fig. 1 shows the

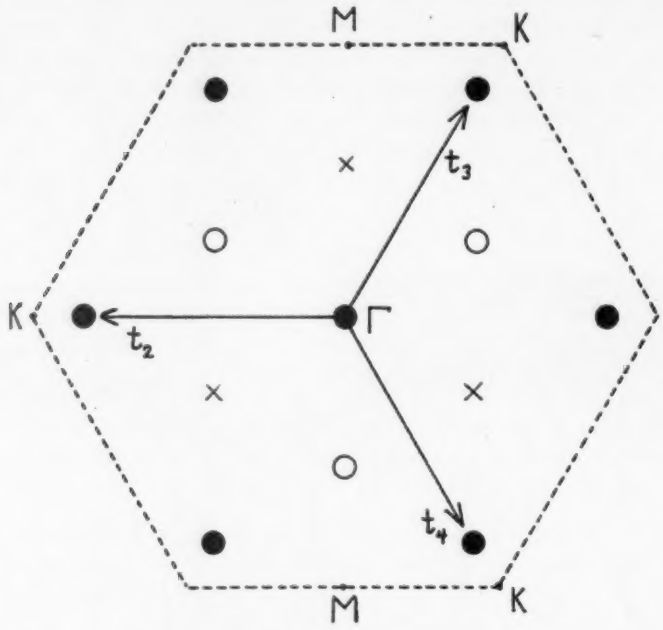


FIG. 1.

positions occupied by atoms in the simplest crystals of this type.[10] The plane of the figure is the plane of t_2 and t_3. The black circles are the positions of atoms in the plane of the drawing, and the open circles are the projections of the positions of atoms in parallel planes a distance $t_1/2$ above or below this plane. The point group consists of the following operations (arranged in classes):

[10] These positions may be described in terms of the space group operations as the points where a threefold axis which is *not* also a sixfold screw axis intersects a symmetry plane perpendicular to it.

$\mathfrak{e}$.

$\mathfrak{d}_6$, $\mathfrak{d}_6^{-1}$: rotations through $\pm 60°$ about an axis parallel to $\boldsymbol{t}_1$; $\mathfrak{d}_6$ will be specified as a counterclockwise rotation in the plane of Fig. 1, i.e., one which takes each point $\boldsymbol{x}$ into a point $\boldsymbol{x}' = \mathfrak{d}_6\boldsymbol{x}$ which is 60° counterclockwise from $\boldsymbol{x}$.

$\mathfrak{d}_3 = \mathfrak{d}_6^2$, $\mathfrak{d}_3^{-1}$.

$\mathfrak{d}_2 = \mathfrak{d}_6^3$.

$\mathfrak{d}'_{2_i}$ $(i = 2, 3, 4)$: rotations through 180° about axes parallel respectively to $\boldsymbol{t}_2$, $\boldsymbol{t}_3$, and $\boldsymbol{t}_4 = -(\boldsymbol{t}_2 + \boldsymbol{t}_3)$.

$\mathfrak{d}''_{2_i}$ $(i = 2, 3, 4)$: rotations through 180° about axes perpendicular to $\boldsymbol{t}_1$ and perpendicular respectively to $\boldsymbol{t}_2$, $\boldsymbol{t}_3$, and $\boldsymbol{t}_4$.

$\mathfrak{i}$: the inversion.

$\sigma_3 = \mathfrak{i}\mathfrak{d}_6$, σ_3^{-1}.

$\sigma_6 = \mathfrak{i}\mathfrak{d}_3$, σ_6^{-1}.

$\varrho = \mathfrak{i}\mathfrak{d}_2$.

$\varrho'_i = \mathfrak{i}\mathfrak{d}'_{2_i}$ $(i = 2, 3, 4)$.

$\varrho''_i = \mathfrak{i}\mathfrak{d}''_{2_i}$ $(i = 2, 3, 4)$.

In designating space group operations below, the origin of coördinates will be taken at the central black circle in Fig. 1.

The first Brillouin zone for such a crystal is a hexagonal prism, shown in Fig. 2. A top view of this prism has been drawn dotted in Fig. 1 also, so as to show its orientation relative to the atomic positions; the scale of this dotted hexagon relative to the rest of Fig. 1 is of course arbitrary. The points labeled Γ, A, M, K, L, H, represent the only kinds of points of symmetry: Tables I to III give, for each of these points $\boldsymbol{k}$, the characters of all representations of G^k/T^k which have wave vector $\boldsymbol{k}$. The points P, Δ, Σ, R, S, T, U, are general points of lines of symmetry: in Tables IV to IX are given, for the $G^{k'}$ of each of these and for each of the above symmetry points $\boldsymbol{k}$, the characters of all representations of $G^{k'}/T^{k}$ which have wave vector $\boldsymbol{k}$. The first and second columns of each table give respectively the number of elements, and an enumeration of the elements, in

each class of the G^k/T^k for the point occurring first in the table. For the sake of simplicity the same notation has been used for elements of these factor groups as for elements of the space group, i.e., each coset is designated by some one of its elements. The G^k/T^k of the point or points occurring farther to the right in the table is obtained from that of the first point by identifying one or more translations with the identity. In enumerating the elements of the classes, a

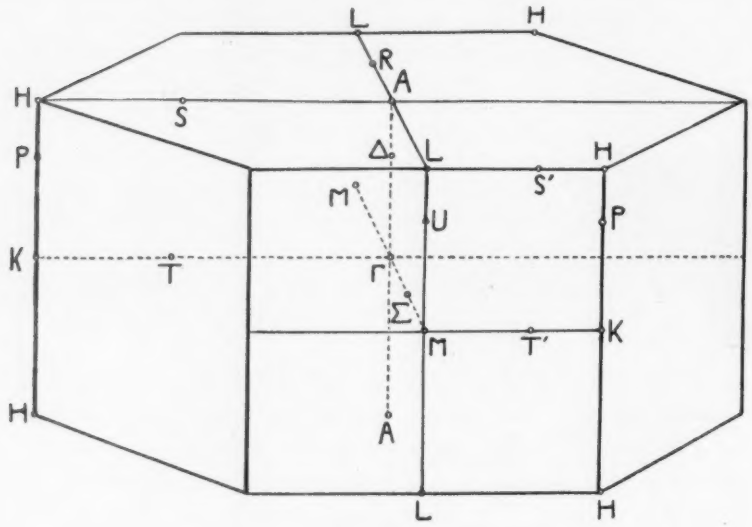


FIG. 2.

condensed notation has been employed: for example, in Table I, $\{\mathfrak{d}_6, \mathfrak{d}_6^{-1}|\tau, \tau + t_1\}$ stands for the four elements $\{\mathfrak{d}_6|\tau\}$, $\{\mathfrak{d}_6^{-1}|\tau\}$, $\{\mathfrak{d}_6|\tau + t_1\}$, and $\{\mathfrak{d}_6^{-1}|\tau + t_1\}$. The subscript i always takes on the three values 2, 3, 4: thus in Table I, $\{\varrho'_i|0\}$ stands for $\{\varrho'_2|0\}$, $\{\varrho'_3|0\}$, and $\{\varrho'_4|0\}$. For some points it is convenient to designate the representations not merely by a subscript numeral, but by such a numeral together with a superscript + or −. Characters for + and − representations are given in the same column. The symbol ω is used for $e^{2\pi i/3}$.

TABLE I.

48		A_1	A_2	A_3	$\Gamma_1^{\pm}$	$\Gamma_2^{\pm}$	$\Gamma_3^{\pm}$	$\Gamma_4^{\pm}$	$\Gamma_5^{\pm}$	$\Gamma_6^{\pm}$
1	$\{\mathfrak{E}\|0\}$	2	2	4	1	1	1	1	2	2
1	$\{\mathfrak{E}\|t_1\}$	−2	−2	−4						
4	$\{\mathfrak{d}_6, \mathfrak{d}_6^{-1}\|\tau, \tau + t_1\}$	0	0	0	1	1	−1	−1	−1	1
2	$\{\mathfrak{d}_3, \mathfrak{d}_3^{-1}\|0\}$	2	2	−2	1	1	1	1	−1	−1
2	$\{\mathfrak{d}_3, \mathfrak{d}_3^{-1}\|t_1\}$	−2	−2	2						
2	$\{\mathfrak{d}_2\|\tau, \tau + t_1\}$	0	0	0	1	1	−1	−1	2	−2
6	$\{\mathfrak{d}'_{2i}\|\tau, \tau + t_1\}$	0	0	0	1	−1	1	−1	0	0
6	$\{\mathfrak{d}''_{2i}\|0, t_1\}$	0	0	0	1	−1	−1	1	0	0
2	$\{\mathfrak{i}\|\tau, \tau + t_1\}$	0	0	0	±1	±1	±1	±1	±2	±2
4	$\{\sigma_3, \sigma_3^{-1}\|0, t_1\}$	0	0	0	±1	±1	∓1	∓1	∓1	±1
4	$\{\sigma_6, \sigma_6^{-1}\|\tau, \tau + t_1\}$	0	0	0	±1	±1	±1	±1	∓1	∓1
2	$\{\mathfrak{g}\|0, t_1\}$	0	0	0	±1	±1	∓1	∓1	±2	∓2
3	$\{\mathfrak{g}'_i\|0\}$	2	−2	0	±1	∓1	±1	∓1	0	0
3	$\{\mathfrak{g}'_i\|t_1\}$	−2	2	0						
6	$\{\mathfrak{g}''_i\|\tau, \tau + t_1\}$	0	0	0	±1	∓1	∓1	±1	0	0

τ is a vector from the atom at the origin to any one of its nearest neighbors in the plane above or the plane below the plane of Fig. 1. Its projection on the plane of Fig. 1 thus goes from the origin to one of the open circles.

TABLE II

32		L_1	L_2	$M_1^{\pm}$	$M_2^{\pm}$	$M_3^{\pm}$	$M_4^{\pm}$
1	$\{\mathfrak{E}\|0\}$	2	2	1	1	1	1
1	$\{\mathfrak{E}\|t_1\}$	−2	−2				
2	$\{\mathfrak{d}'_{22}\|\tau_2, \tau_2 + t_1\}$	0	0	1	−1	1	−1
2	$\{\mathfrak{d}''_{22}\|0, t_1\}$	0	0	1	1	−1	−1
2	$\{\mathfrak{d}_2\|\tau_2, \tau_2 + t_1\}$	0	0	1	−1	−1	1
2	$\{\mathfrak{i}\|\tau_2, \tau_2 + t_1\}$	0	0	±1	±1	±1	±1
1	$\{\mathfrak{g}'_2\|0\}$	2	−2	±1	∓1	±1	∓1
1	$\{\mathfrak{g}'_2\|t_1\}$	−2	2				
2	$\{\mathfrak{g}''_2\|\tau_2, \tau_2 + t_1\}$	0	0	±1	±1	∓1	∓1
2	$\{\mathfrak{g}\|0, t_1\}$	0	0	±1	∓1	∓1	±1
·	Products of above classes with $\{\mathfrak{E}\|t_3\}$ have characters negatives of those listed						

$\tau_2 = t_1/2 - (t_2 + 2t_3)/3$ is the vector from the origin to an atom in the next layer whose projection on the plane of Fig. 1 is in the direction of M (or of the projection of L).

TABLE III

72		H_1	H_2	H_3	K_1	K_2	K_3	K_4	K_5	K_6
1	$\{\varepsilon\|0\}$	2	2	2	1	1	1	1	2	2
1	$\{\varepsilon\|t_1\}$	−2	−2	−2						
2	$\{\delta_3\|t_2\}$, $\{\delta_3^{-1}\|2t_2\}$	2	−1	−1	1	1	1	1	−1	−1
2	$\{\delta_3\|t_1+t_2\}$, $\{\delta_3^{-1}\|t_1+2t_2\}$	−2	1	1						
6	$\{\delta'_{2i}\|\tau_i, \tau_i+t_1\}$	0	0	0	1	1	−1	−1	0	0
2	$\{\sigma_3\|2t_2\}$, $\{\sigma_3^{-1}\|t_1+t_2\}$	0	$i\sqrt{3}$	$-i\sqrt{3}$	1	−1	1	−1	−1	1
2	$\{\sigma_3\|t_1+2t_2\}$, $\{\sigma_3^{-1}\|t_2\}$	0	$-i\sqrt{3}$	$i\sqrt{3}$						
2	$\{\varrho\|0, t_1\}$	0	0	0	1	−1	1	−1	2	−2
6	$\{\varrho''_i\|\tau_i, \tau_i+t_1\}$	0	0	0	1	−1	−1	1	0	0
·	Products of each of above classes with $\{\varepsilon\|t_2\}$ and $\{\varepsilon\|2t_2\}$ have characters respectively ω and ω^2 times those listed above									

τ_i is the vector from the origin to a nearest neighbor atom in the next layer, whose projection on the plane of Fig. 1 is perpendicular to t_i, and whose component normal to this plane is $t_1/2$.

The third class listed consists of a clockwise and a counterclockwise 120° rotation about an axis through one of the points × in Fig. 1. Its product with $\{\varepsilon|t_2\}$ consists of a clockwise rotation about an axis through a black circle and a counterclockwise rotation about an axis through an open circle; its product with $\{\varepsilon|2t_2\}$ consists of a counterclockwise rotation about an axis through a black circle and a clockwise rotation about an axis through an open circle. The classes involving σ_3 are analogously constituted.

TABLE IV

24		$\Delta_1(A)$	$\Delta_2(A)$	$\Delta_3(A)$	$\Delta_4(A)$	$\Delta_5(A)$	$\Delta_6(A)$	$\Delta_1(\Gamma)$	$\Delta_2(\Gamma)$	$\Delta_3(\Gamma)$	$\Delta_4(\Gamma)$	$\Delta_5(\Gamma)$	$\Delta_6(\Gamma)$
1	$\{\varepsilon\|0\}$	1	1	1	1	2	2	1	1	1	1	2	2
2	$\{\delta_6, \delta_6^{-1}\|\tau\}$	$-i$	i	$-i$	i	i	$-i$	1	−1	1	−1	−1	1
2	$\{\delta_3, \delta_3^{-1}\|0\}$	1	1	1	1	−1	−1	1	1	1	1	−1	−1
1	$\{\delta_2\|\tau\}$	$-i$	i	$-i$	i	$-2i$	$2i$	1	−1	1	−1	2	−2
3	$\{\varrho'_i\|0\}$	1	1	−1	−1	0	0	1	1	−1	−1	0	0
3	$\{\varrho''_i\|\tau\}$	$-i$	i	i	$-i$	0	0	1	−1	−1	1	0	0
·	Products of above classes with $\{\varepsilon\|t_1\}$ have characters negatives of those listed												

τ is a vector from the origin to an atom in the next layer, whose component normal to the plane of Fig. 1 is $t_1/2$.

TABLE V

36		$P_1(H)$	$P_2(H)$	$P_3(H)$	$P_1(K)$	$P_2(K)$	$P_3(K)$
1	$\{\varepsilon\|0\}$	1	1	2	1	1	2
2	$\{\delta_3\|t_2\}$, $\{\delta_3^{-1}\|2t_2\}$	1	1	−1	1	1	−1
3	$\{\varrho''_i\|\tau_i\}$	$-i$	i	0	1	−1	0
·	Products of each of above classes with $\{\varepsilon\|t_2\}$ and $\{\varepsilon\|2t_2\}$ have characters respectively ω and ω^2 times those listed above						
·	Products of above classes with $\{\varepsilon\|t_1\}$ have characters negatives of those listed						

τ_i is as defined under Table III.

TABLE VI

16		$U_1(L)$	$U_2(L)$	$U_3(L)$	$U_4(L)$	$U_1(M)$	$U_2(M)$	$U_3(M)$	$U_4(M)$
1	$\{\varepsilon\|0\}$	1	1	1	1	1	1	1	1
1	$\{\delta_2\|\tau_2\}$	$-i$	i	i	$-i$	1	−1	−1	1
1	$\{\varrho'_2\|0\}$	1	1	−1	−1	1	1	−1	−1
1	$\{\varrho''_2\|\tau_2\}$	$-i$	i	$-i$	i	1	−1	1	−1
·	Products of above classes with $\{\varepsilon\|t_3\}$ have characters negatives of those listed								
·	Products of above classes with $\{\varepsilon\|t_1\}$ have characters negatives of those listed								

τ_2 is as defined under Table II (or Table III).

TABLE VII

		Σ_1, R_1	Σ_2, R_2	Σ_3, R_3	Σ_4, R_4
1	$\{\varepsilon\|0\}$	1	1	1	1
1	$\{\delta''_{22}\|0\}$	1	1	−1	−1
1	$\{\varrho\|0\}$	1	−1	−1	1
1	$\{\varrho'_2\|0\}$	1	−1	1	−1
·	Products of preceding classes with any $\{\varepsilon\|t\}$ have characters equal to those above times				
·	$e^{-ik\cdot t}$ ($k = \Sigma$ or R)				

τ_2 is as defined under Table II (or Table III).

TABLE VIII

24		$S_1(H)$	$T_1(K)$	$T_2(K)$	$T_3(K)$	$T_4(K)$	$S_1(A)$
1	$\{\mathfrak{E}\|0\}$	2	1	1	1	1	2
1	$\{\mathfrak{E}\|t_1\}$	−2					−2
2	$\{\tilde{\mathfrak{o}}'_{22}\|\tau_2, \tau_2+t_1\}$	0	1	1	−1	−1	0
2	$\{\underline{\varrho}\|0, t_1\}$	0	1	−1	−1	1	0
2	$\{\underline{\varrho}''_2\|\tau_2, \tau_2+t_1\}$	0	1	−1	1	−1	0
·	Products of above classes with $\{\mathfrak{E}\|t_2\}$ and $\{\mathfrak{E}\|2t_2\}$ have characters						
·	respectively ω and ω^2 times those listed above						

τ_2 is as defined under Table II (or Table III).

TABLE IX

16		$S_1(L)$	$T_1(M)$	$T_2(M)$	$T_3(M)$	$T_4(M)$	$T_1(\Gamma)$	$T_2(\Gamma)$	$T_3(\Gamma)$	$T_4(\Gamma)$
1	$\{\mathfrak{E}\|0\}$	2	1	1	1	1	1	1	1	1
	$\{\mathfrak{E}\|t_1\}$	−2								
2	$\{\tilde{\mathfrak{o}}'_{22}\|\tau_2, \tau_2+t_1\}$	0	1	1	−1	−1	1	1	−1	−1
2	$\{\underline{\varrho}\|0, t_1\}$	0	1	−1	−1	1	1	−1	−1	1
2	$\{\underline{\varrho}''_2\|\tau_2, \tau_2+t_1\}$	0	1	−1	1	−1	1	−1	1	−1
·	Products of above classes with $\{\mathfrak{E}\|t_3\}$ have characters									
·	negatives of those listed									

Several things need to be pointed out in connection with the tables. It will be noticed that in Fig. 1 a clockwise rotation of the Brillouin zone through 30° would bring the point K opposite one of the open circles; for the point diametrically opposite K, which we may call $-K$, a counterclockwise rotation would be needed. This distinction between K and $-K$ arises from the fact that we have made a particular choice of origin of coördinates. If the origin had been chosen at one of the atomic sites represented by open circles, K would have been associated, in the manner just described, with a counterclockwise rotation instead of a clockwise one. It can easily be seen that the characters for

$-K$ are just the complex conjugates of those for K. Similarly the characters for the points $-H$ and $-P$ diametrically opposite H and P respectively, are the complex conjugates of those for H and P.

Another thing to be noted is that if in Fig. 2 we prolong the dotted line ΓK beyond K, the points on the prolonged portion of the line are equivalent to points (such as the one labeled T') on a parallel line through M. So if we identify all equivalent points of k-space, we can say that if we start going to the left from Γ, we reach K, then M, then $-K$, and finally return to Γ. Similarly if we start moving to the left from A, we reach, in order, H, L, $-H$, and A again. In Tables VIII and IX, each representation $T_j(\Gamma)$ goes continuously into $T_j(K)$ and $T_j(M)$ as we follow the path just described, and finally returns to the same $T_j(\Gamma)$ we started with. For the points S of the corresponding line in the top face of the Brillouin zone there is only one irreducible representation S_1, so if we start from $S_1(A)$ we of course end up with $S_1(A)$. The same simple connectivity holds in Table VII for the representations Σ_j for the points Σ of the line $\Gamma M\Gamma$, and for the representations R_j for the points R of the line ALA. But for the vertical lines the connectivity relation is more complicated. In Table IV, for example, $\Delta_1(\Gamma)$ goes continuously into $\Delta_1(A)$ as we pass upward from Γ to A. (It is assumed that the upward direction in Fig. 2 is the direction in which $\boldsymbol{t}_1$ points.) Continuing in the same direction an equal distance brings us back to Γ, but changes our $\Delta_1(A)$ continuously into $\Delta_2(\Gamma)$. Thus the representation which has been designated by $\Delta_1(A)$ is really no more closely related to $\Delta_1(\Gamma)$ than to $\Delta_2(\Gamma)$, and the assignment of a particular subscript to it is rather arbitrary. We find three cycles of this type as we move upward along the line $\Gamma A\Gamma$:

$$\Delta_1(\Gamma) \to \Delta_1(A) \to \Delta_2(\Gamma) \to \Delta_2(A) \to \Delta_1(\Gamma),$$
$$\Delta_3(\Gamma) \to \Delta_3(A) \to \Delta_4(\Gamma) \to \Delta_4(A) \to \Delta_3(\Gamma),$$
$$\Delta_5(\Gamma) \to \Delta_5(A) \to \Delta_6(\Gamma) \to \Delta_6(A) \to \Delta_5(\Gamma).$$

Similarly in Table V, as we move upward along KHK:

$$P_1(K) \to P_1(H) \to P_2(K) \to P_2(H) \to P_1(K),$$
$$P_3(K) \to P_3(H) \to P_3(K).$$

And in Table VI, moving upward along MLM:

$$U_1(M) \rightarrow U_1(L) \rightarrow U_2(M) \rightarrow U_2(L) \rightarrow U_1(M),$$
$$U_3(M) \rightarrow U_3(L) \rightarrow U_4(M) \rightarrow U_4(L) \rightarrow U_3(M).$$

SPACE GROUP O_h^7 (DIAMOND TYPE)

The translation group is that of the face centered cubic lattice, which is generated by three fundamental translations t_{xy}, t_{yz}, and t_{zx}, in the directions of the face diagonals of a cube. These are illustrated in Fig. 3, which shows also the

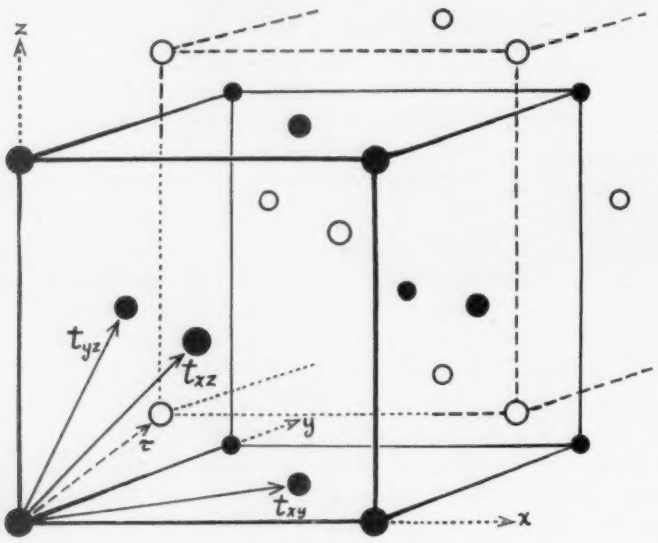


FIG. 3.

positions occupied by atoms in the simplest crystals of this type.[11] These atomic positions are most conveniently visualized as those of two face centered cubic lattices displaced relatively to each other by a quarter of a cube diagonal. To aid in the visualization, sites of one of these lattices are represented by black circles, those of the other by open circles. The point group consists of the following operations

[11] These positions may be described in terms of the space group operations as the points possessing tetrahedral symmetry (point group T_d).

(arranged in classes):

$\mathfrak{d}_{4i}$, $\mathfrak{d}_{4i}^{-1}$ $(i = x, y, z)$: rotations through $\pm$ 90° about the x-, y- and z-axes, respectively,

$\mathfrak{d}_{2i} = \mathfrak{d}_{4i}^{2}$ $(i = x, y, z)$,

$\mathfrak{d}_{3s}$, $\mathfrak{d}_{3s}^{-1}$ $(s = xyz, \bar{x}yz, x\bar{y}z, \bar{x}\bar{y}z)$: rotations through $\pm$ 120° about axes along the diagonals of cubes in the various octants,

$\mathfrak{d}_{2p}$ $(p = xy, yz, zx, \bar{x}y, \bar{y}z, \bar{z}x)$: rotations through 180° about axes halfway between two coördinate axes,

$\mathfrak{i}$: the inversion,

$\sigma_{4i} = \mathfrak{i}\mathfrak{d}_{4i}$, σ_{4i}^{-1} $(i = x, y, z)$,
$\varrho_i = \mathfrak{i}\mathfrak{d}_{2i}$ $(i = x, y, z)$,
$\sigma_{6s} = \mathfrak{i}\mathfrak{d}_{3s}$, σ_{6s}^{-1} $(s = xyz$, etc.),
$\varrho_p = \mathfrak{i}\mathfrak{d}_{2p}$ $(p = xy$, etc.).

In designating space group operations in the tables below, the origin of coördinates will be taken at one of the black atomic sites in Fig. 3, so that if a right-handed coördinate system is used the origin atom has a nearest neighbor in the first octant.

The first Brillouin zone is a truncated octahedron, shown in Fig. 4. The only kinds of points of symmetry are those labeled Γ, X, W, L. Representative points of the various kinds of lines of symmetry are Σ, Λ, Δ, Z, Q. Tables X and XI give, for X and W, the characters of all representations of G^k/T^k which have wave vector $\boldsymbol{k}$; Tables XII and XIII give, for $\boldsymbol{k}' = \Delta$ and Z and $\boldsymbol{k} = X$, the characters of all representations of $G^{k'}/T^k$ which have wave vector $\boldsymbol{k}$. The notation is the same as that described above for the hexagonal space group.

For Γ, L, Λ, Σ, and Q, and for the limiting forms $\Delta(\Gamma)$ of the representation Δ as $k \to 0$, the group G^k/T^k or $G^{k'}/T^k$ is the direct product of a translation group with a point group, so the characters for the representations at these points can be taken from the tables given in reference 1 for the ordinary face centered lattice. For Γ and $\Delta(\Gamma)$ there is no possibility of ambiguity in the use of these tables, since the matrix representing any $\{\alpha|\boldsymbol{a}\}$ depends only on α and

not on $\boldsymbol{a}$. For the other points we must decide which of the various operations $\{\alpha|\boldsymbol{a}+\boldsymbol{t}\}$ going with a given α should be assigned the character given for α in the table of reference 1. For the points Λ and Σ, our choice is made unique by the requirement that the limiting forms $\Lambda(\Gamma)$, $\Sigma(\Gamma)$, of the representations must coincide with those given in reference 1. Suppose $\{\alpha|\boldsymbol{a}\}$ to occur in the group of the wave vector for Λ or Σ, and suppose n to be the smallest integer for which

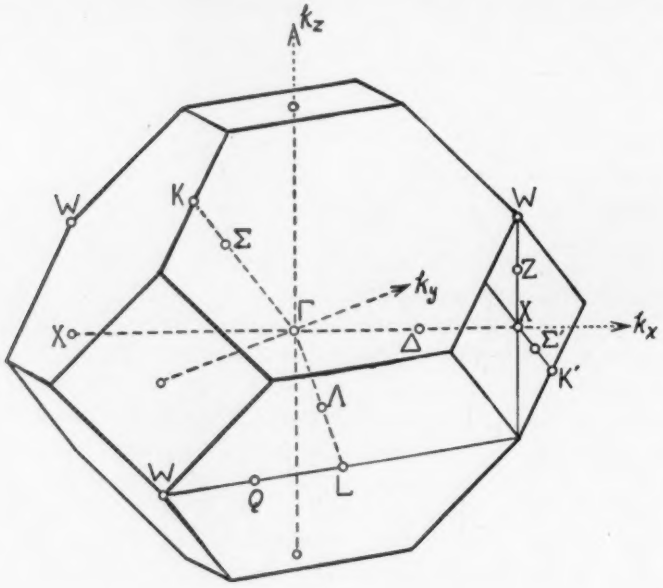


FIG. 4.

$\alpha^n = \varepsilon$. Then if we choose $\boldsymbol{t}$ so that $\{\alpha|\boldsymbol{a}+\boldsymbol{t}\}^n = \{\varepsilon|\mathbf{o}\}$ it is clear that $\{\alpha|\boldsymbol{a}+\boldsymbol{t}\}$ must be assigned the same character as that given for α in the table of reference 1. For L and Q, we may notice that G^L (of which G^Q is a subgroup) consists of the products of elements of the translation group with a set of point operations about a point halfway between two nearest neighbor atoms, these atoms being so chosen that the line joining them is parallel to the line ΓL. We may therefore choose some such point, and assign to each point operation about it the same character as that given for this point

operation in the table of reference 1. The characters obtained in this way will be independent of the way in which the point is chosen, since any two such points must differ by a translation of the lattice, so that corresponding rotations about the two points belong to the same class of G^L.

TABLE X

32		X_1	X_2	X_3	X_4
1	$\{\varepsilon\|0\}$	2	2	2	2
1	$\{\varepsilon\|t_{xy}\}$	−2	−2	−2	−2
4	$\{\delta_{2y}, \delta_{2z}\|0, t_{xy}\}$	0	0	0	0
1	$\{\delta_{2x}\|0\}$	2	2	−2	−2
1	$\{\delta_{2x}\|t_{xy}\}$	−2	−2	2	2
4	$\{\delta_{4x}, \delta_{4x}^{-1}\|\tau, \tau + t_{xy}\}$	0	0	0	0
2	$\{\delta_{2yz}\|\tau\}, \{\delta_{2\bar{y}z}\|\tau + t_{xy}\}$	0	0	2	−2
2	$\{\delta_{2yz}\|\tau + t_{xy}\}, \{\delta_{2\bar{y}z}\|\tau\}$	0	0	−2	2
2	$\{\imath\|\tau, \tau + t_{xy}\}$	0	0	0	0
4	$\{\varrho_y, \varrho_z\|\tau, \tau + t_{xy}\}$	0	0	0	0
2	$\{\varrho_x\|\tau, \tau + t_{xy}\}$	0	0	0	0
4	$\{\sigma_{4x}, \sigma_{4x}^{-1}\|0, t_{xy}\}$	0	0	0	0
2	$\{\varrho_{yz}, \varrho_{\bar{y}z}\|0\}$	2	−2	0	0
2	$\{\varrho_{yz}, \varrho_{\bar{y}z}\|t_{xy}\}$	−2	2	0	0

$\tau = \frac{1}{4}(t_{xy} + t_{yz} + t_{zx})$ is the vector from the origin atom to its nearest neighbor in the first octant.

TABLE XI

32		W_1
1	$\{\varepsilon\|0\}$	2
1	$\{\varepsilon\|t_{yz}\}$	$-2i$
1	$\{\varepsilon\|t_{xy}\}$	−2
1	$\{\varepsilon\|t_{zx}\}$	$2i$
2	$\{\delta_{2z}\|0, t_{xy}\}$	0
2	$\{\delta_{2z}\|t_{yz}, t_{zx}\}$	0
4	$\{\delta_{2xy}\|\tau + t_{yz}, \tau + t_{zx}\}, \{\delta_{2\bar{x}y}\|\tau, \tau + t_{xy}\}$	0
4	$\{\delta_{2xy}\|\tau, \tau + t_{xy}\}, \{\delta_{2\bar{x}y}\|\tau + t_{yz}, \tau + t_{zx}\}$	0
8	$\{\sigma_{4z}, \sigma_{4z}^{-1}\|0, t_{yz}, t_{xy}, t_{zx}\}$	0
4	$\{\varrho_x\|\tau, \tau + t_{xy}\}, \{\varrho_y\|\tau + t_{yz}, \tau + t_{zx}\}$	0
4	$\{\varrho_x\|\tau + t_{yz}, \tau + t_{zx}\}, \{\varrho_y\|\tau, \tau + t_{xy}\}$	0

τ is as defined under Table X.

TABLE XII

16		$\Delta_1(X)$	$\Delta_2(X)$	$\Delta_2'(X)$	$\Delta_1'(X)$	$\Delta_5(X)$
1	$\{\mathfrak{E}\|0\}$	1	1	1	1	2
1	$\{\mathfrak{d}_{2x}\|0\}$	1	1	1	1	−2
2	$\{\mathfrak{d}_{4z}, \mathfrak{d}_{4z}^{-1}\|\tau\}$	$-i$	i	i	$-i$	0
2	$\{\mathfrak{g}_y, \mathfrak{g}_z\|\tau\}$	$-i$	$-i$	i	i	0
2	$\{\mathfrak{g}_{yz}, \mathfrak{g}_{yz}\|0\}$	1	−1	1	−1	0
·	Products of above classes with $\{\mathfrak{E}\|t_{xy}\}$ have characters negatives of those listed					

τ is as defined under Table X.

TABLE XIII [12]

8		$Z_1(X)$
1	$\{\mathfrak{E}\|0\}$	2
1	$\{\mathfrak{E}\|t_{xy}\}$	−2
2	$\{\mathfrak{d}_{2z}\|0, t_{xy}\}$	0
2	$\{\mathfrak{g}_x\|\tau, \tau + t_{xy}\}$	0
2	$\{\mathfrak{g}_y\|\tau, \tau + t_{xy}\}$	0

[12] The existence of a single two-dimensional representation Z_1 has been pointed out by F. Hund, *Zeits. f. Phys.*, 99, 119 (1936).

τ is as defined under Table X.

This table shows that no matter where Z is on the line XW, the only elements of G^Z with nonvanishing characters in Z_1 are the translations.

It should be noticed that points on the prolongation of the line ΓK beyond K are equivalent to points Σ' on $K'X$, since K and K' are equivalent. Thus if we identify equivalent points of k-space, the sequence of points as we proceed along this line is Γ, K, X, $-K$, and Γ. The connectivity is simple, each representation $\Sigma_j(\Gamma)$ returning to $\Sigma_j(\Gamma)$ as we proceed from Γ along this path and back to Γ (cf. the discussion for the hexagonal space group). The same property is possessed by the representations Λ_j as we proceed along $\Gamma L \Gamma$, and of course by the single representation Z_1 as we proceed from X to W to the point where the k_y axis meets the boundary of

the Brillouin zone (a point of the same kind as X, but not equivalent to it), and from there to $-W$ and back to X. However, as we go in the positive x direction along $\Gamma X \Gamma$, the representations Δ_j change continuously according to the following cycles.[13]

$$\Delta_1(\Gamma) \to \Delta_1(X) \to \Delta'_2(\Gamma) \to \Delta'_2(X) \to \Delta_1(\Gamma),$$
$$\Delta_2(\Gamma) \to \Delta_2(X) \to \Delta'_1(\Gamma) \to \Delta'_1(X) \to \Delta_2(\Gamma),$$
$$\Delta_5(\Gamma) \to \Delta_5(X) \to \Delta_5(\Gamma).$$

Thus $\Delta_1(X)$ is really no more closely related to $\Delta_1(\Gamma)$ than to $\Delta'_2(\Gamma)$, etc. This possibility of deforming $\Delta_1(\Gamma)$ continuously into $\Delta'_2(\Gamma)$ does not occur for the simpler space group $\mathfrak{D}_h^5$ which was treated in reference 1.

[13] The designation of the various representations Δ_j is the same as that of reference 1.

Sponge Chromium.—A form of sponge, or powdered, chromium metal that under certain conditions attains a purity of 99.8 per cent.—higher than any chromium used in present commercial manufacturing—has been produced from both low and high grade domestic chromite ores through a process developed by metallurgists of the Bureau of Mines, according to DR. R. R. SAYERS, Director of the Bureau. Immediate benefits of the improved form of chromium metal are expected to be the development of new and important alloying processes in the metal industries of the nation. Its high purity and powdered form render it valuable in the manufacture of special steels, brass and bronze materials, and in alloys that are subjected to high temperatures, such as electrical heating elements. Successfully carried through the laboratory stage to a point where pilot plant tests are justifiable the new reduction process may under favorable circumstances permit the utilization of a large amount of America's "off grade" chromite ores at costs comparable to the existing prices of low carbon ferrochrome. However, its future in this field will depend chiefly upon the availability and cost of chlorine, the chemical used extensively in producing this new metallurgical material. Low temperature reduction without sintering is the basis of the process developed by the Bureau of Mines during five years of research and investigation in obtaining pure chromium metal. The fundamentals consist of the chlorination of chromite ores at elevated temperature, sublimation and separation of volatile chlorides, and reduction of chromium to metal by hydrogen. Sponge chromium of at least 99 per cent. purity may be produced, and if specially purified chloride is used, the product may reach 99.8 purity. Methods and formulas employed in the laboratory production of sponge chromium by the chloride method are described in detail in technical bulletin No. 436 by C. G. Maier, published by the Bureau of Mines.

R. H. O.

DISCOVERY AND DEVELOPMENT OF RADIUM AT GREAT BEAR LAKE.*

BY

CHARLES CAMSELL, LL.D., C.M.G.,

Deputy Minister of Mines and Resources, Canada, and Commissioner of the Northwest Territories.

May I express at the outset my appreciation of the honour you have done me in inviting me to address the members and friends of The Franklin Institute, an institution which has had a long and distinguished record among the scientific institutions of the world.

When Dr. Allen invited me to address The Franklin Institute I found myself in a quandary because any Canadian is today very much restricted in the subjects he may discuss, and very rightly so, because of the dangers of giving aid and comfort to the enemy. War makes a great difference in this respect. However, as more than half of my life has been devoted to the Public Service of Canada and all of that has been concerned with the mineral industry, I thought that a page out of Canada's mining history, dealing with what I consider a most interesting and romantic phase, would be of interest to you.

We have had in Canada a number of interesting events in our mining history; for example, the Cariboo gold rush of 1860 following shortly after the discovery of gold in California; then, thirty-five or forty years later, the great Klondyke stampede, an event which was heralded as one of outstanding romance, but which, in my own experience, had far more of tragedy in it than romance; the Cobalt silver discoveries in 1902, which gave a tremendous fillip to Canadian mining, and the influence of which still remains; and later still, the opening up of the great gold belt extending across northern Ontario and Quebec, which is now providing more than 75 per cent. of Canada's gold output.

These were all milestones in Canada's mining history; but

* Presented at the Stated Meeting held Wednesday, October 15, 1941.

the last major event, that of which I am going to speak tonight, namely, the discovery and development of radium mining to an industry which now occupies the first place in the world, has a romance and interest attached to it not surpassed by any of the others. The interest in this event is accentuated by reason of two facts; first, that the ore deposit is situated on the edge of the Arctic Circle on the bleak and inhospitable shores of Great Bear Lake 1,000 miles in an airline north of

Radium Refinery, Eldorado Gold Mines Ltd., Port Hope, Ont.

the nearest railway point and, second, because radium is the most extraordinary of all the elements that make up the earth's crust.

The element radium, which is associated with uranium in the mineral pitchblende, has, as you know, the peculiar property of being radio-active. The principle of radio-activity was discovered in the year 1896 by Becquerel, only, however, after 50 years of experimental work by his father and his grandfather on the salts of uranium. Two years later, in

1898, Madame Curie and her husband isolated the radioactive element, polonium, and later in the same year discovered radium chloride, though the element itself was not prepared until nearly 12 years later.

The radium industry started in France in 1904. Later, plants were built in Germany, Austria, Portugal, France, England, and the United States. France was the most important producer up to 1914, when the United States took the lead, based upon the carnotite ores of Colorado. The United States was displaced in the lead by Belgium in 1922, when the pitchblende ores of the Belgian Congo came into prominence as a source of radium.

Today, by reason of the discovery in 1930 of rich pitchblende-silver ores on the remote shores of Great Bear Lake in the Northwest Territories and the building of a treatment plant on the shore of Lake Ontario, Canada occupies the most prominent place in the world production of radium. The mine, although temporarily closed down because of the dislocation of the market by the war, is in good shape, with substantial reserves of ore broken or blocked out and with a well-equipped mill capable of handling over 100 tons of ore a day.

The refinery, situated on Lake Ontario, 4,000 miles away from the mine, is operating efficiently and has a capacity to turn out about 100 grams of radium a year in the form of radium bromide and sulphate, as well as polonium, silver, and the three salts of uranium, yellow, orange, and black.

All this has come about in the last 10 years, but the manner in which it has come about constitutes one of the romances of mining in Canada. This is the story which I would like to relate to you and to follow the story by some motion pictures illustrative of the mining, transportation, and treatment of the ore.

Great Bear Lake is situated in northwestern Canada on the rim of the Arctic Circle and is the most northerly of the great lakes of the Continent. The country surrounding the lake is in great part still unknown, unexplored, and unmapped. The lake itself, though one of the great freshwater lakes of the world, has not been fully delineated. The northwestern arm is still indicated on Canadian maps in broken lines.

The first reference to the area dates back to the time of

Alexander Mackenzie. After that explorer's remarkable journey in 1789 to the Arctic Coast, down the river that has since borne his name, he decided to extend the interests of the North-West Company to the lower Mackenzie, and it is presumed he was instrumental in establishing in 1799 a small trading post at the western end of Great Bear Lake, the first establishment in that region.

We next hear of this area when Captain John Franklin, under instructions from the British Admiralty, made his

Mill, adit, and radium concentrate, sacked for shipment, Eldorado Gold Mines.

second expedition to the Arctic. He spent the winter of 1825–26 near the site of this post of Mackenzie's, which by that time had long been abandoned. Dr. John Richardson, who accompanied Franklin as surgeon and naturalist, explored 500 miles of the shores of Great Bear Lake during the fall of 1825 and April, 1826, establishing many points by astronomical observations. These must have been made with extreme care, for his results in the main differ only slightly from those that have since been recorded there by the far superior instruments and methods of today.

Twelve years later, Warren Dease, a Chief Factor of the Hudson's Bay Company, who ably assisted Franklin at his winter quarters in 1825–26, and Thomas Simpson, also an officer of the company, were commissioned to explore the Arctic coast east of the Coppermine, and they spent the winters of 1837–38 and 1838–39 at the northeast end of Great Bear Lake in buildings that were still standing when I visited the lake in 1900. Thomas Simpson, who was a cousin of George Simpson, the famous Governor of the Hudson's Bay Company, was one of the most energetic explorers the company ever had.

In 1848–49, Sir John Richardson again wintered at Great Bear Lake. This melancholy sojourn was on his return from the Arctic expedition which the British Admiralty requested him to undertake in search of Her Majesty's ships, "Erebus" and "Terror." These vessels, with their combined crews of 129 men, had left England in May, 1845, to complete the "northwest passage" and the survey of the north coast. They were under the command of Sir John Franklin, from whom no official word had been received since his letter dated July 12, 1845, Whalefish Islands. His ships were last seen by a whaling captain on July 26th of that year, moored to an iceberg, waiting for an opening in the ice so as to cross to Lancaster Sound.

Between 1850 and the period about which I am going to speak, the district was almost entirely neglected, except by that courageous missionary, Father Emile Petitot, who made as many as eight journeys there during the years 1866 to 1879, residing on each occasion three to six months.

Desolate though it is, Great Bear Lake is unquestionably impressive, especially when seen in its proper setting from the air. On a bright summer day features of topography appear far more clear-cut than they do here, the colour of trees, water, rock, hills, and flowers stand out in beautiful and striking contrasts. The air is wonderfully clear and the colour of the water a pale blue. The aspect in winter is very different.

By the old Athabaska River route, Great Bear Lake is distant 1,550 surveyed miles from Edmonton. It is the largest lake lying wholly in Canada; its area is one-quarter that of England, but when accurately defined, will probably

be found to be somewhat greater than a quarter of that country.

The easterly half constitutes part of the western boundary of the Canadian Shield. The southern and western shores are fairly well wooded when compared with the sparse growth along most of the shore in the northern half, which lies within the Arctic Circle and borders on the treeless, or barren lands.

Mill and oil storage tanks.

The water is the clearest in the world, but, is always cold. On the surface the temperature in August is about 43° F. and 33° F. a short distance underneath.

Ice in the lake seldom breaks up before August 1, remaining one month or more longer than at Great Slave Lake, and drifting usually till August 15. It forms again early in September and covers the entire sheet of water by the end of that month or the first week in October. Navigation of the lake, for its entire extent, is consequently limited to about 50 days in the year.

Climatic conditions are severe and one has to be young and vigorous to endure them the year round. There is, how-

ever, a fascination about the country, especially in the summer and even in the so-called barren lands, which border Great Bear Lake on the north and east.

The appeal of the country can best be expressed in the words of an old Indian that I knew who, in talking to the priest who was attempting to teach him the principles of Christianity, said: "My Father, you have told me of the beauties of heaven. Tell me one thing more. Is it more beautiful than the country of the muskox in the summer time,

Surface plant and camp, Eldorado Gold Mines. Looking southerly; cookhouse and staff quarters in foreground, mill in right distance.

where the mists roll over the hills and the waters are very blue, and the loons cry very often? That is beautiful, and if heaven is still more beautiful, I will be content to rest there until I am very old."

I first became acquainted with Great Bear Lake during the winter I spent at Fort Norman in 1895–96. There was a scarcity of food at the settlement—not an unusual occurrence in those days—and to get food for the dogs I made a snowshoe trip to the lake. This was in February, always a very difficult

and cold month in which to travel these parts, for the days are short and winter temperature at its lowest. We spent ten days with a band of Indians at the southwest end of the lake near the site of Old Fort Franklin, but it was an interesting ten days with little to do except sleep, eat, and sit and watch the primitive gambling games that went on continuously in one of the tepees.

My next visit to Great Bear Lake was in 1900 with a geological survey party designed to explore and map the shores of the lake and perhaps locate the source of native copper, which for generations, the Esquimo had been known to use for implements. The region was then entirely uninhabited and had up to that time been visited by not more than half a dozen explorers.

We had two canoes for a party of five and as I look back at it now I realize that it was a foolhardy expedition that had no business to survive, for it was poorly equipped both in supplies and personnel. However, after some 1,500 miles of travel by canoe from Fort Norman on Mackenzie river and some 600 miles on snowshoes, we accomplished our object and reached the railway at Edmonton just before Christmas, a journey which took some seven months and which I now do in two days by aeroplane.

I do not intend to discuss the incidents of this journey except to mention some things that have a bearing upon the discovery of radium-bearing ores and the present situation with regard to radium.

The season of 1900 was not an unusual one and it was the beginning of August before the main body of the lake was free of ice. By following the strip of open water along the shore, however, we were able to make considerable progress. The middle of August found us traversing the rocky and deeply indented eastern shore of the lake. On the 24th of August we were in Echo bay. The weather was stormy, snow fell occasionally, and in the mornings the temperature was below freezing. The short Arctic summer was almost over. On the cliff at the entrance to Echo bay, where we were stormbound, the rocks were stained by oxidation of the minerals with red, green, yellow, and pink colours. This outcrop was carefully examined and the evidences of iron, copper, uranium, and

cobalt noted, but no particular significance was attached to the occurrence in such a remote and inaccessible part of the country.

In the official report of this expedition published by the Geological Survey of Canada, the following year, appeared this sentence:

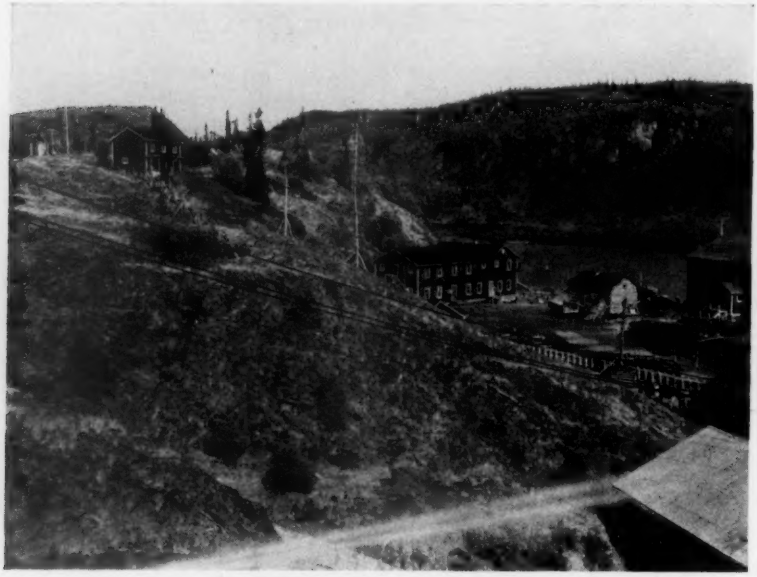
From left at edge of bay; bunkhouse, powerhouse. Left foreground; dry and shop. Right foreground; adit portal.

> "In the greenstones east of McTavish bay occur numerous interrupted stringers of calc-spar containing chalcopyrite, and the steep rocky shores which here present themselves to the lake are often stained with cobalt-bloom and copper-green."

This statement, like so many others in government documents, lay buried in the reports of the Geological Survey until, 30 years later, it caught the eye of an experienced Cobalt mining man who knew the significance of cobalt-bloom. Gilbert LaBine knew the relationship of cobalt-bloom to native silver and set out in the winter of 1930 by aeroplane to

locate and examine the occurrence referred to by the Geological Survey.

With one companion he was landed from the plane some miles south of Great Bear Lake and proceeded northward from that point on foot, drawing his outfit on a toboggan. The party reached Echo Bay in the early spring while the surface of the lake was still fozen, but there was no difficulty in locat-



Office at extreme left; centre building contains cookhouse, dining room and staff quarters.

ing the occurrence of cobalt-bloom referred to in the geological report. A number of claims were staked.

Returning to civilization in the fall, Mr. LaBine had his samples examined by officers of the Mines Department, and his opinion of the presence of pitchblende was confirmed.

In the summer of 1931, without advertising his discoveries, he returned to Great Bear Lake to do some further prospecting. The examinations of that season led him to the conviction that the deposits of silver and pitchblende were well worth developing and a source of radium was indicated. Having

satisfied himself and the Department on this score, it was necessary for him to explore and develop the deposit and for us to find a process for the reduction of the ores and the recovery of the radium.

Efforts were first made by the Department to secure information from the operating companies as to the method of reduction used. These efforts were entirely unsuccessful and it became incumbent upon the Mines Department to develop a process. This was not an easy undertaking because of the complexity of the ore and because of the risks involved to the health of the workers. For example, the ore contains 40 different minerals, of which 35 are metallic minerals, and the contained metals include, besides radium and uranium, silver, copper, lead, zinc, nickel, cobalt, iron, arsenic, chromium, manganese, molybdenum, barium, magnesium, calcium, silica, and sulphur. However, engineers were assigned to the job and after a complete search of the literature on radium and radium-bearing ores, a method was selected which appeared applicable to the Great Bear Lake ores, and tried out on a test-tube scale. Later, as developments proceeded and conditions warranted, a small pilot plant was built in the laboratories of the Mines Department and the process tried out on that scale.

The results were entirely satisfactory and a small quantity of radium bromide was actually produced.

After these research operations had been in progress for some time and the results appeared to be satisfactory, Mr. Pochon, present manager of the Port Hope plant, who is one of the outstanding radium technologists of the world, was engaged by the Mining Company and some time was spent by him in our laboratories collaborating with our officers. The final result was a completed process which was shortly after put into use when the radium plant on Lake Ontario was built.

Production of radium began at the plant in 1933 and has continued up to the present. This plant is now not only the principal source of radium in the world, but it has been able to reduce the price of radium from about $50,000 or $60,000 a gram to about $25,000 a gram. The importance of that accomplishment can only be fully appreciated by those in medical and scientific fields, who had been restricted in the

use of radium by reason of its high price. There are ample supplies of ore at the mine.

In addition to the difficulties of working out a process of extraction there were very serious problems of mining and of transportation to overcome.

Climatic conditions at the mine are severe. Winter temperatures are low and the summer temperature fairly high. The range is from about 60 F. degrees below zero to 85 above.

Mill in foreground.

Timber is sparse and as the ground is permanently frozen within 2 or 3 inches of the surface, no garden stuff can be grown. In a geological sense, one may say that the region has only just emerged from the glacial period, and permanent frost, resulting from the continental ice cap which covered the surface for thousands of years, was found in the mine to a depth of 350 feet. Indeed it would require only a small drop in the annual average temperature to bring about a return of glacial conditions. All food supplies except fish and cariboo meat have to be taken into the country.

Although some of the concentrates have been transported by aeroplane from the mine to the railhead 1,000 miles away, most of this material is now handled by lake and river boat 1,500 miles to the railway and thence 2,500 miles to the reduction works. Navigation, however, on Great Bear Lake is only open for one and a half months of the year, though on the Mackenzie and Athabaska rivers the season of open water is four months. There is only a very short period, therefore, when supplies may be taken in or out.

Altogether, the whole operation of mining, transportation, and treatment required the exercise of a great deal of initiative, courage, and resourcefulness, and that all the difficulties have been overcome is to the lasting credit of Mr. Gilbert LaBine, who has been actuated as much by the laudable motive of providing a service to humanity as by the motive of making a profit.

Today radium can be bought at less than one-half the price prevailing eight years ago. As a consequence, the uses of radium have expanded and instead of being supplied only to hospitals and medical men, I am told that 85 per cent of our output goes today into industries in Great Britain, Canada, and the United States concerned with the production of various kinds of steel.

Urea Treatment of Lumber.—J. F. T. BERLINER (*Mechancial Engineering*, Vol. 64, No. 3.) Green lumber dries by the movement of water toward the drier outside fibers where the water evaporates. This movement continues until the entire piece reaches a moisture content in balance with that of the surrounding air. The outer zone of the drying wood, because it has less moisture, has a lower vapor pressure than the wetter inner zone. This difference in vapor pressure results in the movement of moisture toward the outside. The rate of moisture loss is normally controlled by the temperature and moisture content—or the relative humidity—of the surrounding air. The lower the relative humidity of the air, the faster the evaporation of the surface moisture. However, if the relative humidity is lowered too rapidly, the wood will check severely. The proper control of the relative humidity at the surface of drying lumber is essential to prevent checking. Chemical seasoning of lumber is the process of applying a water soluble hygroscopic anti-shrink chemical to the surface of green lumber to allow the lumber to be air or kiln dried with the minimum of seasoning degrade. Seasoning degrades include splitting, checking, honeycombing (hollow horning), warping, and internal collapse. The chemical penetrates the surface zone of the green lumber by diffusion, and maintains the outer zone in a relatively moist and swollen condition as the inside of the piece dries. Of all substances considered for chemical seasoning, urea has proved most satisfactory in both laboratory investigations and commercial-scale mill tests. It has many advantages over other materials. To be effective, urea must penetrate and be present in the outer shell of the green lumber. The higher the green moisture content of the wood, the more readily will this penetration take place. It is therefore essential to apply the urea to the green wood as soon as possible after sawing. The quantity of urea required varies with the species, dimensions and cut of lumber. For hardwoods less than 2 in. thick, and soft woods not thicker than 6 in., 40 to 60 lb. of urea per 1000 fbm. of lumber is usually sufficient to maintain seasoning degrade to a minimum. On thick lumber and on boxed-heart pieces, somewhat greater quantities of urea may be required. There are four general methods by which urea may be applied to lumber—dry-spreading, soaking, dipping and spraying.

R. H. O.

SOIL PRESSURE DISTRIBUTION ALONG FLEXIBLE FOUNDATIONS.

BY

ANDERS BULL,

Board of Transportation, City of New York.

Stating the Problem. A problem frequently presenting itself in foundation engineering is how to determine the soil pressure distribution along a flexible slab transmitting its load to an elastically yielding ground. Whereas other indeterminate problems—those pertaining to rigid frames—have been treated at great length in numerous textbooks, comparatively little is to be found on the treatment of flexible foundation slabs, despite their extensive use in modern structures and the important bearing which the pressure distribution has upon the stresses in the slab and the loading of the ground.

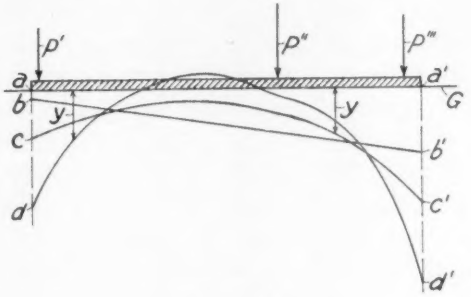


FIG. 1.

For an illustration, let a–a' in Fig. 1 represent the bottom of an unloaded slab resting on the ground G; assume next that a system of loads P is applied to it. The loads will force the slab downward until the sum of the reactions developed in the compressed soil equals the sum of the loads. If the soil is very yielding, or the slab very stiff, it may assume a position b–b', remaining practically straight, while for a stiffer soil, or a more flexible slab, the latter may be deflected into a

curved shape, such as c–c' or d–d'. In any case, the ordinate y of the deflection curve at any point, as measured from the unloaded position a–a', represents the local yield of the soil. In its relation to a–a', the curve will, therefore, be referred to as the *yield curve.*

The yield curve is a function of the span, the loading condition, the flexibility of the slab and the resiliency of the soil. If E be the modulus of elasticity of the material in the slab, and I its moment of inertia, then the product EI is a measure of its flexibility. The resiliency of the soil is expressed by the *soil compression constant* K, representing the load in kips which must be applied to each square foot of soil surface in order to make it yield one inch.

The quite complicated behavior of soil in compression, especially as regards boundary conditions and recovery, will not be entered upon here. A soil will be considered elastically yielding when the amount of yield, by and large, is proportional to the load applied, as will roughly be true for sand, gravel, hardpan, and even for the stiffer clays. Such broad use of the term is justified by the uncertainty usually prevailing in regard to the constant K. In important cases, it is always advisable to determine its approximate value through measurements made at the site, but even with this precaution, accuracy comparable to that obtainable, say, in bridge design is not to be looked for, tests having proved that the value may change considerably within a few feet. Such being the case, refinements adding to the perplexities of the problem seem out of place from an engineering point of view.

Since, accordingly, the pressure exerted against the slab by the soil at any point may be considered equal to the ordinate y times the constant K, the problem resolves itself into determining the shape of the yield curve.

Earlier Methods of Treatment. A general formula has been developed [1] from which the equation of the yield curve may be derived for some of the simplest loading conditions, such as a single load applied at the center of the span, or equal loads

[1] See Föppl: "Vorlesungen über Technische Mechanik," Band III, Teubner, Leipzig, 1900; Timoshenko: "Strength of Materials," Part II, Van Nostrand, New York, 1930.

applied at the ends, as well as for slabs of infinite length; but in the far more common case of asymmetrical loading, occasionally combined with end moments, the difficulties attending the use of the formula practically prohibit its use in engineering work.

Föppl also refers to a graphical method by which a yield curve is first tentatively assumed. Treating the curve as a load diagram, with due regard to the applied loads as well, a funicular polygon is drawn from which the moment diagram for the slab is determined. By next treating this moment diagram as a new load diagram, the deflection curve is found from a second funicular polygon. If the deflection curve thus obtained should happen to be of the same shape as the assumed yield curve it would represent a correct solution. Only by rare coincidence would that be the case, however; a series of revisions of the assumed curve are generally required before that end is achieved, necessitating as many repetitions of the procedure. The graphical method, which seems to be little known in this country, is comparatively simple of application, but the continual repetition of the various operations is both time-consuming and tedious.

The need of simpler and more direct methods for determining soil pressure distribution has long been felt by foundation designers, in particular by those engaged in subway work, where the bottom slab or "invert" transmitting the weight of the structure and overlying soil to the ground below, is subjected to an every varying array of loading conditions. The details presented herewith of two methods approaching the problem in different ways and meeting all reasonable demands for speed, simplicity and accuracy, may therefore be of interest.

A. APPROXIMATE MATHEMATICAL TREATMENT.

Principle Used. For explaining the basic principle of the method, let us assume that the yield curve c–c', Fig. 2, for a given slab and loading condition has been determined. From the known soil pressures and the applied loads, approximate values for the deflection d, as measured from the chord c–c', may then be computed for a number of points in the following way.

Dividing the span into, say, 4 equal parts, *0–1*, *1–2*, *2–3*, *3–4*, and considering the soil pressure on each portion as of a trapezoidal distribution, the pressure, as well as any load applied to the portion, are replaced by equivalent forces acting at its two ends. At junction points, *1*, *2*, *3*, end forces of the same kind are added up, the result being the forces f_0 to f_4 and F_0 to F_4. The forces f, replacing the soil pressure, are directed upward and are considered positive, while forces F, replacing the applied loads, have the opposite direction and sign. The deflections d at the three junction points can now be expressed by general formulas as linear functions of the forces—and end moments, if any. Computed and plotted,

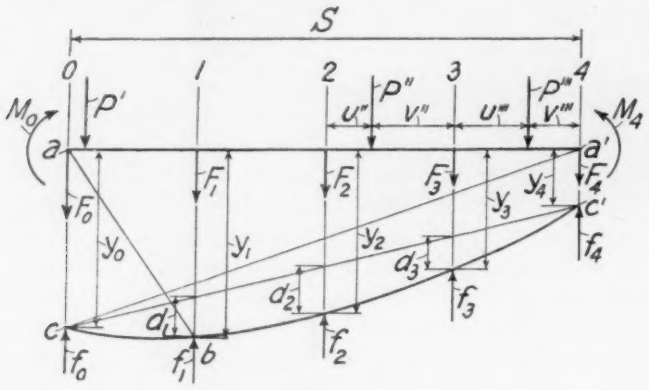


FIG. 2.

using chord c–c' as an axis, the values are found to be close to the yield curve, the small deviations being chiefly due to the substitution of forces for the pressures.

In the method considered, the procedure described above is simply reversed as follows: By equating the unknown deflection d at each junction point to the general formula for the deflection at the same point (see equations (8) below), three simultaneous equations are obtained through the solution of which the particular deflection values may be determined which make such equality possible. From these values, which embody the indeterminate features of the problem, the ordinates y at either end of the span are found by means of two independent equations, the complete yield curve being

thus defined by five known points. Through the application of this principle, any problem in soil pressure distribution may be solved with comparative ease.

Equivalent Forces. For determining the forces f, the supposedly trapezoidal pressure diagram for each portion is divided into two triangles, as shown for portion *0–1* in Fig. 2. Denoting by S the overall span and by W the width of the slab, both being expressed in inches, the force equivalent, say, to the triangle *abc*, is

$$\frac{1}{2}\frac{1}{4}\frac{S}{12}\frac{W}{12}Ky_0 = \frac{SWK}{1152}y_0 \text{ kips},$$

2/3 of which goes to the end point nearest its center of gravity (0), and 1/3 to the other (1). Treating the other triangles the same way, and denoting by T the fraction $\frac{SWK}{1152}$, we have for the forces f:

$$\begin{aligned}
f_0 &= T\left(\frac{2}{3}y_0 + \frac{1}{3}y_1\right)\\
f_1 &= T\left(\frac{1}{3}y_0 + \frac{4}{3}y_1 + \frac{1}{3}y_2\right)\\
f_2 &= T\left(\frac{1}{3}y_1 + \frac{4}{3}y_2 + \frac{1}{3}y_3\right) \qquad (1)\\
f_3 &= T\left(\frac{1}{3}y_2 + \frac{4}{3}y_3 + \frac{1}{3}y_4\right)\\
f_4 &= T\left(\frac{1}{3}y_3 + \frac{2}{3}y_4\right).
\end{aligned}$$

Drawing the line c–a', we may consider the ordinates y_1, y_2, y_3 as being made up of three parts each:

$$\begin{aligned}
y_1 &= d_1 + \frac{3}{4}y_0 + \frac{1}{4}y_4\\
y_2 &= d_2 + \frac{1}{2}y_0 + \frac{1}{2}y_4 \qquad (2)\\
y_3 &= d_3 + \frac{1}{4}y_0 + \frac{3}{4}y_4.
\end{aligned}$$

Substitution in equations (1) gives:

$$
\begin{aligned}
f_0 &= T\left(\frac{1}{3}d_1 + \frac{11}{12}y_0 + \frac{1}{12}y_4\right)\\
f_1 &= T\left(\frac{4}{3}d_1 + \frac{1}{3}d_2 + \frac{3}{2}y_0 + \frac{1}{2}y_4\right)\\
f_2 &= T\left(\frac{1}{3}d_1 + \frac{4}{3}d_2 + \frac{1}{3}d_3 + y_0 + y_4\right) \qquad (3)\\
f_3 &= T\left(\frac{1}{3}d_2 + \frac{4}{3}d_3 + \frac{1}{2}y_0 + \frac{3}{2}y_4\right)\\
f_4 &= T\left(\frac{1}{3}d_3 + \frac{1}{12}y_0 + \frac{11}{12}y_4\right).
\end{aligned}
$$

The forces F, replacing the applied loads P', P'' $\cdots$, are obtained by splitting up each load into its reaction counterparts acting at the ends of the portions, and combining at junction points. For instance:

$$F_3 = \frac{u''}{u'' + v''}P'' + \frac{v'''}{u''' + v'''}P''', \qquad (4)$$

where u and v are the distances from the load considered to the ends of the portion at which it is applied.

General Deflection Formulas. A positive sign will be used for deflections directed downward and for moments stretching the bottom fibers of the slab. Considering the slab freely supported at points *o* and *4*, Fig. 3, the deflection d_F produced

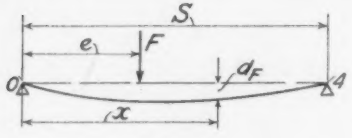


FIG. 3.

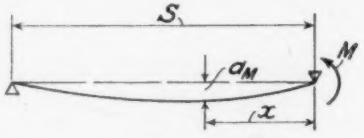


FIG. 4.

at a distance x from *o* by a force F applied at a distance e from *o*, where $e \gtrless x$, is given by the standard formula

$$d_F = -\frac{F}{6EI}\frac{e(S-x)}{S}(e^2 - 2Sx + x^2). \qquad (5)$$

For $e > x$, symbols e and x in equation (5) are interchanged (Maxwell's theorem).

On the other hand, the deflection d_M, Fig. 4, produced at a distance x from one end of the span as the result of a moment M being applied at that end, is found to be

$$d_M = \frac{M}{6EI}\left(\frac{x^3}{S} + 2Sx - 3x^2\right). \qquad (6)$$

Since we are here dealing only with deflections produced at the junction points *1*, *2*, *3* by forces and moments applied at points *0* to *4*, the distances e and x will be multiples of $S/4$. This makes it possible to reduce equations (5) and (6) to the following simple forms:

$$d_F = \frac{S^3}{1536EI} FA \qquad \text{and} \qquad d_M = \frac{S^2}{1536EI} \frac{MB}{S}, \qquad (7)$$

in which A and B are coefficients to be taken from the table below.

TABLE 1.

Values of Coefficients A and B in Equations (7).

Force.	A_1.	A_2.	A_3.	Moment.	B_1.	B_2.	B_3.
F_1, f_1	−18	−22	−14	M_0	+84	+96	+60
F_2, f_2	−22	−32	−22	M_4	+60	+96	+84
F_3, f_3	−14	−22	−18				

In the table, the suffix to a coefficient at the head of a column refers to the point for which the deflection is to be determined; while the suffix to a force or end moment refers to the point of application of such force or moment.

Example. In a span of 180 in., freely supported at points *0* and *4* (Fig. 2), a force of − 25 kips, is applied at point *3*, and an end moment of + 840 in.-kips, at point *4*. The resulting deflection at point *1* is to be determined.

$F_3 = -25$ is multiplied by the value given for A_1 opposite F_3, and $M_4 = +840$ by the value given for B_1 opposite M_4,

and we have:

$$d_1 = \frac{180^3}{1536EI}\left[(-25) \times (-14) + \frac{840 \times 60}{180} \right]$$

$$= \frac{3797}{EI} \times 610 \text{ in.}$$

With several forces and moments acting on the slab, the total deflections at the junction points are, accordingly:

$$d_1 = \frac{S^3}{1536EI}\left[-18(F_1 + f_1) - 22(F_2 + f_2) \right.$$
$$\left. - 14(F_3 + f_3) + 84\frac{M_0}{S} + 60\frac{M_4}{S} \right]$$

$$d_2 = \frac{S^3}{1536EI}\left[-22(F_1 + f_1) - 32(F_2 + f_2) \right.$$
$$\left. - 22(F_3 + f_3) + 96\frac{M_0}{S} + 96\frac{M_4}{S} \right] \quad (8)$$

$$d_3 = \frac{S^3}{1536EI}\left[-14(F_1 + f_1) - 22(F_2 + f_2) \right.$$
$$\left. - 18(F_3 + f_3) + 60\frac{M_0}{S} + 84\frac{M_4}{S} \right].$$

Determining the Yield Curve. Equations (3) contain ten unknown quantities, these being the forces f_0 to f_4, the deflections d_1 to d_3, and the two end ordinates y_0 and y_4. For a solution, we have the five equations (3) and the three equations (8), while two more equations are furnished by the conditions of static equilibrium, the latter two equations reading:

For counter-clockwise rotation about point (0), Fig. 2,

$$(F_4 + f_4)S + (F_1 + f_1)\frac{1}{4}S + (F_2 + f_2)\frac{2}{4}S$$
$$+ (F_3 + f_3)\frac{3}{4}S - M_0 + M_4 = 0. \quad (9)$$

For lateral movement,

$$F_0 + f_0 + F_1 + f_1 + F_2 + f_2$$
$$+ F_3 + f_3 + F_4 + f_4 = 0. \quad (10)$$

By a simple, though somewhat lengthy, process of substitution and reduction, which for the sake of brevity is omitted here, equations (8) are brought into the following forms, letter Q standing for the quantity $\frac{1536EI}{S^3} \times \frac{6}{T}$:

$$\begin{aligned}
(17 + Q)d_1 + 78d_2 + 3d_3 &= \frac{3}{2T}\left(60F_0 - 15F_1 \right. \\
&\quad \left. - 34F_2 - 5F_3 + 48F_4 + 348\frac{M_0}{S} + 228\frac{M_4}{S} \right) \\
12d_1 + (116 + Q)d_2 + 12d_3 &= \frac{3}{2T}\left(76F_0 - 12F_1 \right. \\
&\quad \left. - 52F_2 - 12F_3 + 76F_4 + 384\frac{M_0}{S} + 384\frac{M_4}{S} \right) \qquad (11) \\
3d_1 + 78d_2 + (17 + Q)d_3 &= \frac{3}{2T}\left(48F_0 - 5F_1 \right. \\
&\quad \left. - 34F_2 - 15F_3 + 60F_4 + 228\frac{M_0}{S} + 348\frac{M_4}{S} \right),
\end{aligned}$$

while equations (9) and (10) are reduced to:

$$\begin{aligned}
y_0 &= -\frac{5}{8}d_1 - \frac{1}{4}d_2 + \frac{1}{8}d_3 - \frac{1}{16T}\left(8F_0 + 5F_1 \right. \\
&\quad \left. + 2F_2 - F_3 - 4F_4 + 12\frac{M_0}{S} - 12\frac{M_4}{S} \right) \\
y_4 &= +\frac{1}{8}d_1 - \frac{1}{4}d_2 - \frac{5}{8}d_3 + \frac{1}{16T}\left(4F_0 + F_1 \right. \\
&\quad \left. - 2F_2 - 5F_3 - 8F_4 + 12\frac{M_0}{S} - 12\frac{M_4}{S} \right).
\end{aligned} \qquad (12)$$

After solving the three simultaneous equations (11) for d_1, d_2 and d_3, the values found are substituted in equations (12), yielding the end ordinates y_0 and y_4. By finally substituting for d_1, d_2, d_3, y_0 and y_4 in equations (2), we obtain the remaining ordinates y_1, y_2 and y_3.

Typical Example. The comparative simplicity of the method is illustrated by the following example. The deflections will here be determined to 4 decimals for the sole purpose of demonstrating the consistency of the results, while in

practice the accuracy obtainable with a slide rule will generally be sufficient.

A 5 ft. strip of a subway invert having an overall span S of 480 in. (Fig. 5) and comprising a wide flange beam embedded

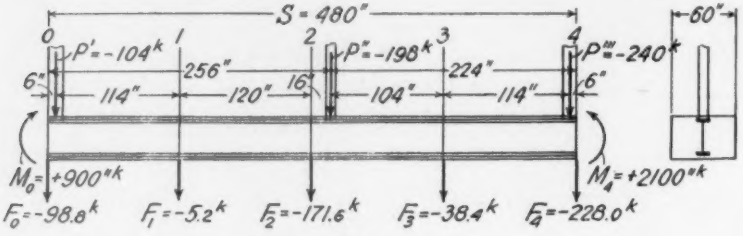


FIG. 5.

in concrete, is subjected to the loads P', P'', P''' and the end moments M_0 and M_4. The points of application and values of the loads, as well as the directions and values of the moments, are indicated in the diagram. The invert is located above ground water so that no portion of the soil reaction is hydrostatic.

The beam has a moment of inertia I of 6857 in.^{4}, that of the concrete being disregarded; the modulus of elasticity E is taken at 29000 k./sq. in., and the value of the constant K at 8 k./sq. ft. We have, therefore:

$$T = \frac{480 \times 60 \times 8}{1152} = 200; \quad \frac{3}{2T} = 0.0075; \quad \frac{1}{16T} = 0.000313;$$

$$Q = \frac{1536 \times 29000 \times 6857}{480^3} \times \frac{6}{200} = 82.855.$$

After resolving the loads into their equivalent forces F_0 to F_4, whose amounts are given at the bottom of Fig. 5, the values of the constant terms (right-hand parentheses) in equations (11) and (12) are determined. The calculations are conveniently arranged as in Table 2, the first figure in a column being the coefficient, the second figure the product obtained by multiplying it by the value of F or M/S, as given in the first column. The five products in each line are obtained with one setting of the slide rule, or one dialing of the calculating machine.

TABLE 2.

Determining Values of Constant Terms in Equations (11) and (12).

	Eqs. (11).			Eqs. (12).	
$F_0 = -98.8$	+ 60 − 5928	+ 76 − 7509	+ 48 − 4742	+ 8 −790	+ 4 − 395
$F_1 = -5.2$	− 15 + 78	− 12 + 62	− 5 + 26	+ 5 − 26	+ 1 − 5
$F_2 = -171.6$	− 34 + 5834	− 52 + 8923	− 34 + 5834	+ 2 −343	− 2 + 343
$F_3 = -38.4$	− 5 + 192	− 12 + 461	− 15 + 576	− 1 + 38	− 5 + 192
$F_4 = -228.0$	+ 48 −10944	+ 76 −17328	+ 60 −13680	− 4 +912	− 8 +1824
$\frac{M_0}{S} = +1.875$	+348 + 653	+384 + 720	+228 + 428	+12 + 23	+12 + 23
$\frac{M_4}{S} = +4.375$	+228 + 998	+384 + 1680	+348 + 1523	−12 − 53	−12 − 53
Total	− 9117	−12991	−10035	−239	+1929
Multiply by	+0.0075	+0.0075	+0.0075	−0.000313	+0.000313
Result	−68.378	−97.433	−75.263	+0.0747	+0.6028

Equations (11) accordingly take the form:

$$\begin{aligned} 99.855d_1 + 78.000d_2 + 3.000d_3 &= -68.378 \\ 12.000d_1 + 198.855d_2 + 12.000d_3 &= -97.433 \\ 3.000d_1 + 78.000d_2 + 99.855d_3 &= -75.263. \end{aligned} \tag{13}$$

The values satisfying equations (13) are:

$$d_1 = -0.3241 \text{ in.}; \quad d_2 = -0.4466 \text{ in.}; \quad d_3 = -0.3952 \text{ in.} \tag{14}$$

Substituting for d_1, d_2 and d_3 in equations (12), we find:

$$y_0 = +0.2026 + 0.1116 - 0.0494 + 0.0747 = +0.3395 \text{ in.}$$
$$y_4 = -0.0405 + 0.1116 + 0.2470 + 0.6028 = +0.9209 \text{ in.}$$

and from equations (2):

$$y_1 = -0.3241 + 0.2546 + 0.2302 = +0.1607 \text{ in.}$$
$$y_2 = -0.4466 + 0.1698 + 0.4604 = +0.1836 \text{ in.}$$
$$y_3 = -0.3952 + 0.0849 + 0.6907 = +0.3804 \text{ in.}$$

By plotting the values of y_0 to y_4, we obtain for the yield curve the broken line shown in Fig. 6. For a comparison, the yield curve obtained from a model is indicated by the dashed curve. Since, in the model, the span was divided into 12 parts, as compared to 4 in the method described, the result should, theoretically, be more accurate. It is possible, of course, to increase the accuracy of computed results by the

same means, but in view of the uncertain behavior of the soil it would hardly be worth while. By dividing the span into 5 parts, 6 points might be plotted, as compared to the 5 points above, but 4 simultaneous equations would then have to be

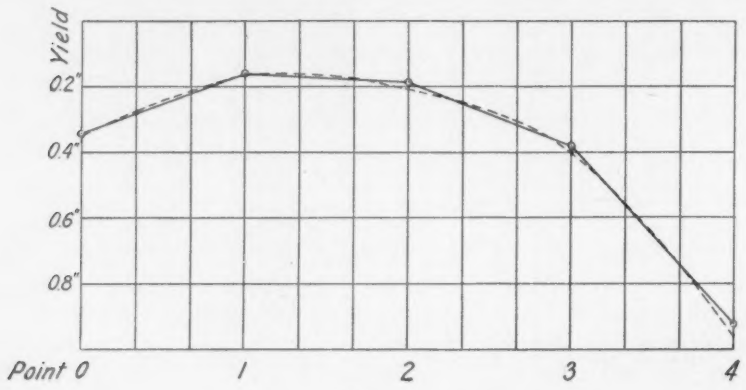


FIG. 6.

solved instead of 3, complicating the calculations to a degree out of proportion to the slight advantage gained which, for all we would know, may be illusory.

Consistency of Results. The value of T being 200, equation (1) gives for the forces f the amounts indicated in Table 3.

TABLE 3.

Point.	f.	F.	$F+f$.	$\frac{M}{S}$.	Products as per Table 1.		
					Point 1.	Point 2.	Point 3.
0	+ 55.98	− 98.8		+1.875	+ 157.5	+ 180.0	+ 112.5
1	+ 77.75	− 5.2	+ 72.55		−1305.9	−1596.1	−1015.7
2	+ 85.03	−171.6	− 86.57		+1904.5	+2770.2	+1904.5
3	+175.07	− 38.4	+136.67		−1913.4	−3006.7	−2460.1
4	+148.15	−228.0		+4.375	+262.5	+ 420.0	+ 367.5
Total	+541.98	−542.0			− 894.8	−1232.6	−1091.3
Deflection d = Total $\times \frac{S^3}{1536\,EI}$ =					−0.3240	−0.4463	−0.3952

Their sum is found to be + 541.98, agreeing closely with the sum of the applied loads, or forces F, − 542.0. Multiplying

the resulting force $(F + f)$ and the M/S value at each point by the respective coefficients in Table 1, adding up the products and multiplying the totals by $S^3/1536EI = 0.3621 \times 10^{-3}$, in accordance with equations (8), we obtain values for the deflections d_1, d_2 and d_3 which are seen to agree with those in equations (14) within the limits of unavoidable error.

B. MODEL ANALYSIS.

The Model. The slab is represented by the brass wire r (Fig. 7) and the soil by the uniformly spaced and equally

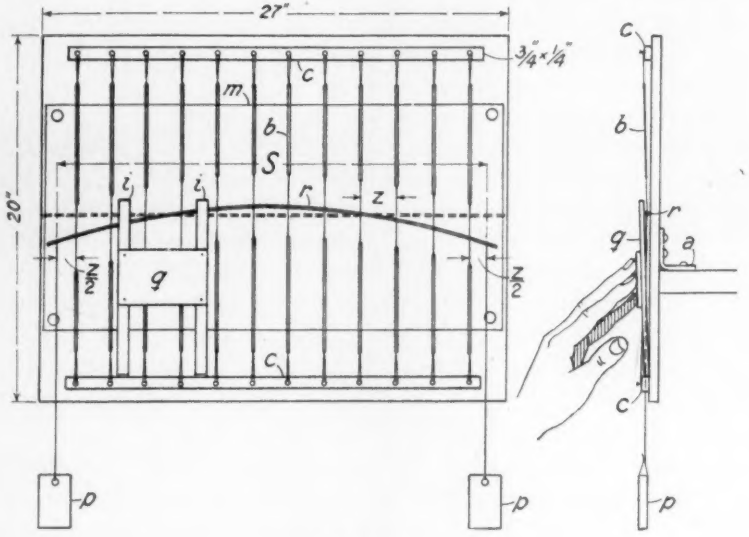


FIG. 7.

stretched rubber bands b between which the wire is held suspended. The resilient bands resist a vertical displacement of the flexible wire in much the same manner as does the resilient soil a displacement of the flexible slab. Assuming the same relation to obtain between resiliency and flexibility in both cases, then, if the wire is loaded with weights which are proportional to the loads applied to the slab at corresponding points, it will be forced downward and bent into a curve similar to the one assumed by the prototype. The ordinate of the curve at any point of the wire bears the same proportion

to the average ordinate as does the soil pressure at the corresponding point of the slab to the average soil pressure, and since the latter is known, being the total load divided by the area of the slab, the soil pressure at any point is easily determined.

Component Parts. Models were early used in the Board of Transportation for the design of subway inverts. Two pictures showing their general makeup were printed in *Civil Engineering* for April, 1932, in a discussion of a paper on the supporting of subways; but on account of space limitation, essential details bearing on similitude and operation had to be omitted. In these models, helical springs were used to represent the soil; while entirely satisfactory for the purpose, springs are an impediment in so far as they have to be either coiled by the prospective user or made to order. This drawback is removed by the substitution of easily obtainable rubber bands. Though bands eventually disintegrate, they will retain their elastic features for months if freshly made.

An assortment of wires of different thickness should be on hand. So-called "brass drill rods" (or "decimal size rods"), a standard product of the American brass industry, are recommended. The rods, which are useful also for other types of models,[2] come in straight lengths of 3 ft. and in a great variety of sizes, of which gauge Nos. 40 to 50 (diam. 0.098″ to 0.070″) are most suitable for the type here considered.

Resiliency of Bands. The stress-strain characteristics of rubber, expressed by the curve *a–a* in Fig. 8, would seem, offhand, to preclude the use of rubber bands for the purpose indicated, the curve showing no portion within which stress and strain are proportional. The material has, besides, the undesirable quality of "creep," or a certain time lag between stress and strain. However, if excessive stretching of the bands is avoided, the lag is a matter of one to two minutes only and may be disregarded, while the lack of proportionality is compensated for by the pairing of the bands.

Supposing *a–a* to be the elastic curve of the upper bands (Fig. 7), then the lower bands are represented by the curve *b–b*. With the wire *r* in its unloaded position, corresponding

[2] See *Eng. News-Record*, Dec. 8, 1927; *Civil Engineering*, Aug., 1937.

to the point of intersection i in Fig. 8, the bands in each pair are equally stretched to about 2.5 times their original length, exerting the same amount of pull in opposite directions. A downward displacement y of the wire increases the pull of the upper band and reduces the pull of the lower. Within the zone h, where the bands are stretched to between 2 and 3 times their original length, the slopes of curves a–a and b–b vary at about the same rate, but in opposite sense. The stress/strain quotient of the band pair as a unit remains, therefore, practi-

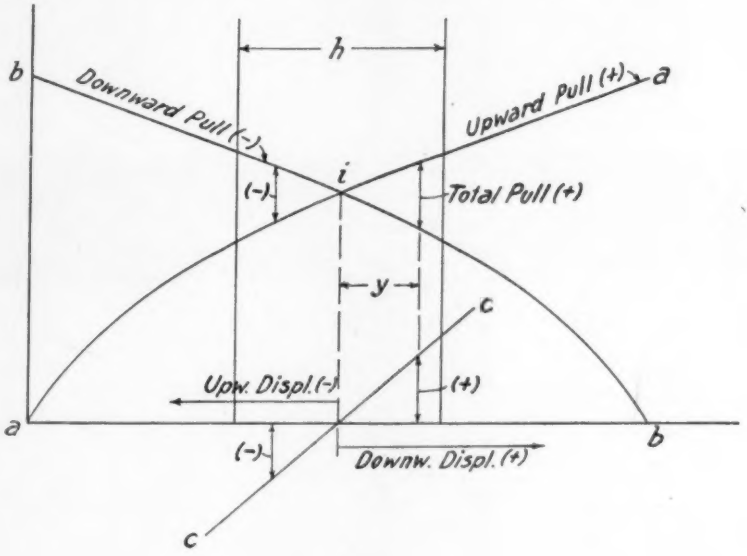


FIG. 8.

cally constant and the resultant total pull on the wire may be represented by the line c–c.

Sorting of Bands. In order that the upper and lower bands shall coöperate in the manner just described, they must be of the same initial length and resiliency. Bands of uniform length may easily be had, but their resiliency will, as a rule, differ considerably, and a sorting is therefore necessary. This is quickly done by means of the contrivance shown in Fig. 9.

A piece of wood w with three evenly spaced nails n_1, n_2, n_3 and a light pointer h is tied by the center nail n_2 to a lever

pivoted at o, the throw of which is limited by the nails n_4 and n_5. Two rubber bands b_1, b_2 are strung between nails n_1, n_2 and two more nails n_6, n_7, driven through the pieces t into the board.

By throwing the lever into the position shown by dashed lines, the bands are stretched to about 3 times their initial length. If they are of the same resiliency the piece w is displaced without rotation, whereas any inequality is revealed by a tilting of the pointer which plays over the scale s. If the piece w is light enough it will be lifted clear of the board and there will be no disturbing friction.

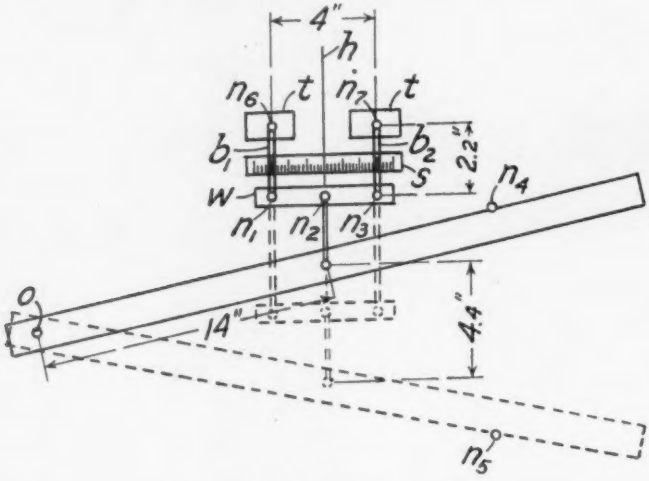


FIG. 9.

Without removing the band b_1, which may be tied in place, another band is substituted for b_2 and the test repeated. If the pointer is tilted less than, say, $\pm$ 1:50 the band is retained for use in the model. Of a lot tested in this way, about five per cent. of the bands met the requirement, each test taking but a few seconds.

Loops of uniform width are next made from pieces of stout sewing thread by knitting their ends together about a flat piece of wood about 2 in. wide, using a weaver's knot to prevent slipping (see Fig. 10). The loops are tied to opposite sides of the bands b which are then connected into pairs by

threading them into one another as shown. In this way, a good, non-slipping grip is obtained on the wire *r* held between them.

Spacing of Bands. Bands spaced far apart correspond to a more resilient soil, and vice versa. Therefore, having selected a wire, one can always, by properly adjusting the spacing *z* (Fig. 7), attain the desired relationship between resiliency and flexibility. The spacing to be used in any specific case is found as follows:

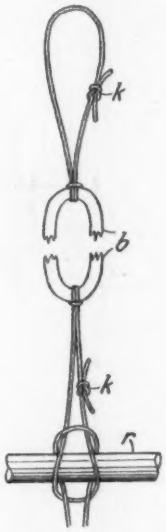


FIG. 10.

The wire *r* (Fig. 11) is fastened in the clamping device *g* and a band pair *b* is attached to it at a distance *L* from the support. The band pair is stretched to the same length as in the model by attaching its outer loops to nails *n* in the wooden frame *f* which can be moved at right angles to the undeflected wire by sliding it against the strip *j*.

Moving the frame by an amount *e*, measured on the scale *u*, the simultaneous deflection *d* of the wire is observed on a similar scale *v*, using the knot on one of the inner loops for a target, oblique sighting being guarded against by glueing scale *v* to a mirror *m*.

The yield y of the band pair will then be the difference $e-d$, giving for the relation between deflection and yield:

$$\frac{d}{y} = \frac{d}{e-d}.$$

Spaced z in. apart, as measured in the scale adopted for the model, each band pair represents the soil supporting $zW/144$ sq. ft. of the slab, W being the slab width in inches. A yield

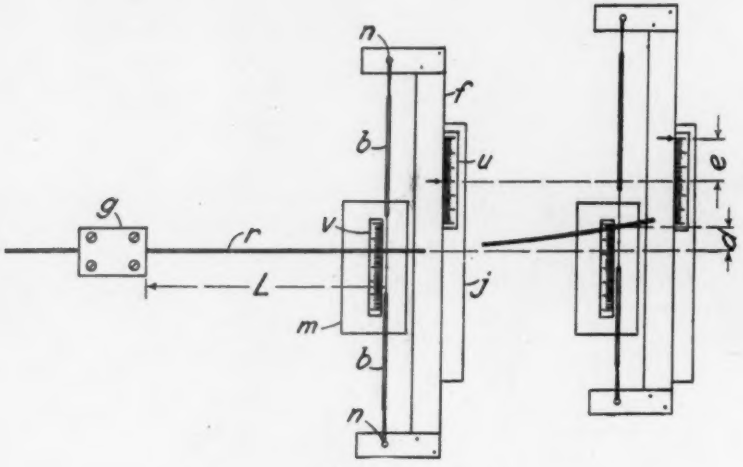


FIG. 11.

of Y in. over such an area produces a soil reaction R, amounting to:

$$R = \frac{zWYK}{144} \text{ kips},$$

K being the soil compression constant. If a force of that amount were applied at the free end of a cantilever of the same material and cross section as the slab and having a length equivalent to L (Fig. 11), as measured in the model scale, the resulting end deflection D would be:

$$D = \frac{RL^3}{3EI} = \frac{zWYKL^3}{432EI} \text{ in.} \qquad (15)$$

The correct relation between slab and model is secured when

$$\frac{D}{Y} = \frac{d}{y}, \qquad \text{or} \qquad D = \frac{d}{y} Y.$$

Substituting the latter value for D in formula (15), we find for z:

$$z = \frac{432EI}{WKL^3} \times \frac{d}{y} \text{ in.} \tag{16}$$

The usual number of band pairs in a model is from 6 to 12. If the value obtained for z gives a higher number, a thinner wire is tried, and vice versa. With the outer two pairs placed at a distance $z/2$ from the ends of the span S (Fig. 7), the quotient S/z should be a whole number. This added requirement may likewise make it necessary to try another wire, though slight discrepancies may be overlooked in view of the uncertainty of the constant K.

Having determined the spacing, vertical lines, spaced z in. apart, are drawn on a sheet of paper m (Fig. 7) and on the horizontal cleats c into which nails n are driven, centering on the lines. The band pairs are tied to the wire, as shown in Fig. 10, and strung between the nails, being thus stretched to about 2.5 times their initial length, and the inner loops are slid along the wire until they are directly over the lines on the paper. Extra lines are drawn through the end points of the span and through load points, for aligning the load strings. A re-alignment of the loops and strings is necessary after the loads have been applied since the bending of the wire causes a shortening of its horizontal projection.

Recording the Yield Curve. The position of the wire before and after applying the weights p (Fig. 7) is recorded as follows: Pressing the wire firmly against the paper by means of the frame q which is steadied against the lower cleat, a pencil or ruling pen is run along the upper side of the wire portion held between the prongs i, the frame being successively moved from one end of the span to the other. In order that the pressure shall not upset the board, the latter is conveniently supported by two angle irons a at the end of a drawing table, as shown in the right hand view of Fig. 7.

Accuracy. For demonstrating the accuracy of model results, an example has been chosen which is simple enough for a strict, theoretical treatment. A one-ft. strip of a reinforced concrete foundation slab having an overall span of 216 in. is loaded at the ends with equal loads to a total of P kips. The following values are assumed:

$$E = 2000 \text{ k./sq. in.} \qquad I = 730 \text{ in.}^4 \qquad K = 9 \text{ k./sq. ft./in.}$$

Referring to Fig. 11, the deflection d of a 47 gauge brass drill rod at a distance $L = 8$ in. was found to be 53.5 units (60-scale) for a displacement e of 100 units, giving for the corresponding yield: $y = 100 - 53.5 = 46.5$ units. A span of 24 in. was used in the model, its scale being thus 24 : 216, or 1 : 9. Measured in this scale, L is equivalent to a slab cantilever of $8 \times 9 = 72$ in.; therefore, according to formula (16):

$$z = \frac{432 \times 2000 \times 730}{12 \times 9 \times 72^3} \times \frac{53.5}{46.5} = 18 \text{ in.},$$

giving for the corresponding number of band pairs: $216/18 = 12$.

After recording the neutral position of the wire, equal weights were applied at the ends of the span, producing a sag of about 2 in., and the deflected position was recorded. The vertical distance y between the two records was measured at 1 in. intervals and the average y_a determined. y_a is the model equivalent of the average yield Y_a of the slab, for which we have:

$$Y_a = \frac{P}{\text{Area of slab in sq. ft.} \times K} = \frac{P}{162} \text{ in.}$$

By multiplying y at any point by the quotient Y_a/y_a, the yield at the corresponding point of the slab is obtained, the result, in inch per kip of total load, being the graph shown by a dashed line in Fig. 12.

The theoretical method gives for the yield per kip in this case:

$$y = 10^{-3}[2.940 \sin ax(e^{ax} - e^{-ax}) - 1.558 \cos ax(e^{ax} - e^{-ax})] \text{ in.}, \quad (17)$$

where:

x = Distance from center of span, in in. (see Fig. 12),
y = Yield of slab at distance x, in in.,
e = Base of natural logarithms = 2.718 $\cdots$;

and

$$a = \sqrt[4]{\frac{K}{48EI}}.$$

The corresponding graph is indicated by the solid line in Fig. 12. For the points represented by vertical lines in the

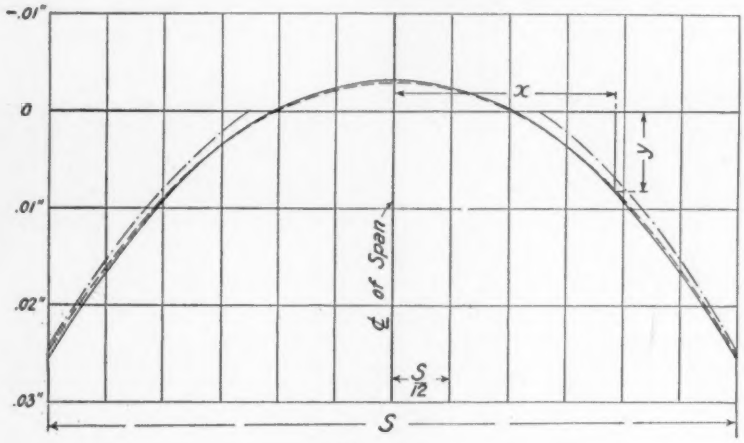


FIG. 12.

diagram, the yields, in units of 1/10,000 of an inch, compare as follows:

Model:	249	163	90	35	−2	−21	−29	−22	−2	36	90	163	251
Theory:	255	167	92	35	−3	−24	−31	−24	−3	35	92	167	255

Negative Soil Pressure. In long spans it frequently happens that a portion of the graph is on the negative side of the zero line, as in Fig. 12. Theoretically, the soil is here stressed in tension, but as this is inconsistent with the behavior of soil the net result is that no pressure is exerted on that portion. Elimination of the negative pressure, however, changes the entire yield curve. Its shape, in this case, cannot be determined by the theoretical method represented by formula

(17) since the mathematical functions become discontinuous, whereas it is easily accomplished with a model by simply detaching the band pairs that are deflected upwards. If this is done in the above example we obtain the curve indicated by a dash-dot line in Fig. 12.

Actually, however, the dead weight of the slab produces a certain amount of yield *before* load is applied; this initial yield must first be overcome before there can be any tendency toward negative soil pressure. Assuming our slab to weigh 140 lb. per sq. ft., the initial yield will be $0.140/K = 0.016$ in. As the maximum negative deflection is 0.0031 in. per kip, the total load would have to exceed 5 kips before negative pressure need be considered.

NOTES FROM THE NATIONAL BUREAU OF STANDARDS.*

AIR RAID WARNING DEVICES.

During the past few months many tests have been made in the Bureau's Sound Section to determine the suitability of commercially available devices for giving air raid warning signals. Sirens operated by electricity, steam, and compressed air; air horns; whistles; and other appliances have been studied. Although no complete report can be published at this time, it seems desirable to make available the data on the devices which have been tested and also to set forth certain facts that should be considered in the purchase and installation of an air raid warning signal system.

All the information now available has, therefore, been incorporated in a Letter Circular, LC685, entitled "Devices for Air Raid Warnings." The supply is limited, but as long as copies are available they will be sent free to officials directly charged with the provision of signal systems for their communities. Requests should be addressed to the Sound Section, National Bureau of Standards, Washington, D. C.

DEAD STORAGE OF AUTOMOBILES.

The prospective dead storage of many passenger automobiles, either for lack of tires or because of the absence of the owners on military duty has resulted in many inquiries as to the best procedure to follow. As considerable misinformation on this subject has been published, the Bureau has prepared a short Letter Circular, LC684, giving information which it is hoped will be useful to the many car owners and will tend to conserve the country's automobiles for satisfactory use later. Requests for this Letter Circular should be addressed to the Automotive Power Plants Section, National Bureau of Standards, Washington, D. C. It is available without charge.

* Communicated by the Director.

PERFORMANCE TEST OF FLOOR COVERINGS.

Building Materials and Structures Report, BMS80, recently released, is the fourth progress report in a series giving results of performance tests of floor coverings suitable for use in low-cost houses. Reports previously issued are BMS34, BMS43, and BMS68. A description of the testing equipment and procedure was given in Technical News Bulletin 289 (May, 1941). Included in this fourth series of installations were cork tiles, rubber tile containing aluminum oxide aggregate, asphalt tile, marbleized linoleums, felt-backed floor coverings having various wearing surfaces, strip maples, maple unit-block, pecan unit-block, asphalt mastic, coal-tar mastic, alumina cement-rubber latex composition, magnesium oxychloride composition, and 1 : 2 : 4 Portland cement concrete. Most of the floor coverings were tested on both concrete and strip-wood subfloors. Different underlays and adhesives were also included in the test.

The report contains brief summaries of the manner in which the various installations performed, the amounts of compression and wear caused by the equipment, and photographs of the floor coverings at the end of the test.

Some conclusions which may be drawn from the several series of performance tests are:

Where trucking is to be done, equipping the truck with rubber-tired wheels in preference to steel-tired wheels will increase the durability of almost all types of floor coverings.

The use of felt or preferably plywood underlays with thin floor coverings over strip-wood subfloors is desirable from the standpoint of both durability and appearance of the surface.

The removal of felt-backed floor coverings cemented directly to strip-wood subfloors is extremely difficult and involves high costs in labor. Where a dry-felt underlay has been used, removal is much easier.

Maple, pecan, oak, ½ inch rock-elm plywood, ⅛ inch rubber, ⅛ inch linoleum, and magnesium oxychloride composition with an aggregate of granite chips and granite dust are durable floor coverings even under severe service. These floors are among those having a high initial cost.

In the lower cost field, the felt-backed floor coverings having wearing surfaces of linoleum composition, cellulose

nitrate composition, and resin-treated cotton-linters sheet showed very good resistance to abrasion. For some types of occupancy, such as would be encountered in most homes, they should render satisfactory and economical service. They do however, need protection against concentrated or indenting loads.

The price of BMS80 is 15 cents. Copies are obtainable from the Superintendent of Documents, Government Printing Office, Washington, D. C.

ULTRAVIOLET RADIATION IN HIGH LATITUDES.

Information on ultraviolet solar and sky intensities in high latitudes is of great biologic interest to the medical profession in connection with the question of the incidence of rickets in children and in the propagation of minute forms of marine plants and animals (diatoms, blue-green algae) called plankton.

In the early spring, long before the sun can shine into the deep fjords in Iceland, the ultraviolet from the sky causes the faces of the inhabitants to take on a ruddy color, that develops into a dark-brown tan in midsummer, when exposed to both the sun and the sky. In Iceland fewer children have rickets than in the Faroe Islands, where there is more cloudiness.

In view of the fact that practically no quantitative data have been available on the amount of ultraviolet solar and sky radiation incident in high latitudes, the Radiometry Section of the Bureau welcomed the opportunity to take part in the Louise A. Boyd Arctic Expedition. Simple, automatic measuring and recording apparatus was installed, whereby, for the first time, a continuous record was obtained, in absolute value, of the intensity of the biologically effective ultraviolet radiation from the entire sky, incident on a horizontal plane under various meteorological conditions, in the polar regions.

The outstanding results of this survey are given in a paper (RP1469) by W. W. Coblentz, F. R. Graceley, and R. Stair in the May *Journal of Research*. In the highest latitudes visited (78° N.), in the summer months when the sun

is at its highest elevation (24°), the ultraviolet intensities are high and much the same as observed in the latitude of Washington during November and December, when the sun, at the noon hour, is practically at the same elevation as in northern Greenland (Etah, latitude 78° N.) in August. Taking into consideration the long period of daylight, in high latitudes during the clearest midsummer days, animal and plant life is exposed to an appreciable amount of ultraviolet radiation that can have a biological effect in metabolism, in the production of vitamin D, and in the prevention of rickets.

AIR PERMEABILITY OF FABRICS.

The ability of clothing to resist the penetration of winds in winter or to permit free circulation of air in summer, and the ability of parachute cloth to permit a limited flow of air and thus absorb the shock of opening are illustrations of the importance of the air permeability of fabrics.

An improved instrument for evaluating this property, which permits any part of a piece of cloth to be measured without cutting, is described by Herbert F. Schiefer and Paul M. Boyland in the May number of the *Journal of Research* (RP1471). A new clamping device is one of the features.

The calibration and operation of the instrument are discussed. Results of measurements on two very different types of fabrics—parachute cloth and blankets—are given for several methods of clamping. A suitable method is described for which the edge leakage is negligible. The random sampling error of the average of 5 tests for air permeability is less than 5 per cent. approximately 9 times out of 10.

HIGH-PURITY IRON.

Cast iron, wrought iron, simple steels, complex alloy steels, in fact all ferrous materials are essentially impure iron and their properties are those of the basic material, iron, modified by the presence of alloying elements, impurities, and factors such as heat treatment and mechanical work. Knowledge of the properties of pure iron is, therefore, essential to an understanding of the effect of different factors on the properties of known metals and to indicate the possibilities and limitations

of new alloys or combinations. The need for accurate information is greater today than ever before because of the demands for greater reliability and for improved or new properties in ferrous materials.

The properties of pure iron have never been determined directly because pure iron (iron which was absolutely free from all impurities) has never been available. The best data are the result of determinations of the properties of the purest available specimens, and the value of most of these data is affected by uncertainty about the accuracy and completeness of the analyses.

Iron of unusual purity has been prepared and many of its properties have been determined at the Bureau. As explained in a paper (RP1472) by H. E. Cleaves and J. M. Hiegel in the *Journal of Research* for May, this iron is unique, among high-purity irons, in the limited number of impurities the presence of which could be detected by the most thorough analysis, and in the small value (0.01 per cent. or less) for the total of all impurities in any one sample. Determinations were made of the workability, microstructure, density, and the thermal, mechanical, electrical, and magnetic properties of this 99.99+ pure iron. The results confirm, and in some cases exceed, the best previously available data.

ELIMINATION OF OXIDE FILMS ON FERROUS MATERIALS.

The growing interest in the use of controlled atmospheres for the heat treatment of metal products is indicated by the large number of papers which are appearing in the literature. In the present emergency when particular stress is being placed on speed, it is not strange that manufacturers of metal parts should make every effort to eliminate time-consuming processes. Such operations as hardening or annealing for stress relief involve the use of high temperatures and if the heating is done in air, oxidation cannot be avoided. The scale that forms is often objectionable and pickling, grinding, or polishing operations may be necessary for its removal. On the other hand, if the heat treatment is carried out in a suitably controlled atmosphere, little or no oxidation will occur, and the part will be in condition for the next step in fabrication with a considerable saving in time and material.

The successful use of controlled atmospheres for heat treatment has followed a period of development in which the effects of various constituents in the atmospheres have been evaluated and the permissible limits of each determined. Different metals require different atmospheres and, in the case of steels, the gas mixture is sometimes adjusted to compensate for variation in carbon content. It would appear that completely inert atmospheres would be satisfactory for heat treatment, but the cost of eliminating the final traces of oxygen makes their use impractical. Vacuum furnaces have also been suggested, but their application has been confined chiefly to experimental work since the heating is limited to specimens of small dimensions.

A paper (RP1468) by Vernon C. F. Holm in the May number of the *Journal of Research* describes the results of vacuum-heating experiments undertaken to determine the behavior of metals in practically inert atmospheres. It was found that ferrous materials could be heated in vacuo without oxidation and also that lightly oxidized specimens of most irons and steels could be brightened by this procedure.

An investigation of the mechanism of this brightening showed that the presence of carbon was essential. Oxidized specimens of iron containing small amounts of carbon were brightened in 15 to 20 minutes at 800° C., and the elimination of the oxide film was accompanied by decreases in the carbon content. Clean-up of oxide films on stainless steel occurred also when the specimens were heated to about 1050° C. Oxidized high-purity iron which contained less than 0.001 per cent. of carbon could not be brightened by vacuum heating at temperatures up to 1250° C. Vacuum heating of lightly oxidized specimens of high-purity iron sometimes caused the oxide film to agglomerate, forming distinct, geometric patterns that could be observed under the microscope.

OXIDATION OF NONFERROUS METALS.

An investigation has been made of the rate of oxidation of 18 nonferrous metals by means of the interference colors of oxide films. With 8 of these metals complete time-temperature diagrams for interference colors were obtained; with

7 metals the approximate forms and positions of the graphs were obtained. Comparison is made between the results obtained with these metals and with typical steels.

As shown in RP1470 by Dunlap J. McAdam, Jr. and Glenn W. Geil, in the May *Journal of Research*, the diagrams obtained with these nonferrous metals are similar to those obtained with steels. (*J. Research* NBS, 23, 63 (July, 1939), RP1221.) For a constant film thickness, the relation between logarithm of temperature and logarithm of oxidation time is linear. The variation of the film thickness either with time at constant temperature or with temperature for constant oxidation time, when plotted with logarithmic coordinates, is represented by a reversed curve. When plotted with Cartesian coordinates, the variation of film thickness with time at constant temperature is represented by a curve without reversal; this is a complex curve becoming approximately parabolic at the upper end.

An attempt is made to correlate the forms and positions of the curves with the affinities of the metals for oxygen, with the resistances at the metal-oxide interface, and with the specific diffusivity of the ions and electrons through the oxide film. The variation of the rate of oxidation with the thickness of the film is such that it may be expressed in terms of an assumed variation of the specific resistance with the film thickness. This means merely that the film behaves as if its specific resistance (not necessarily its electrical resistance) varies in the manner described.

TABLES OF MOMENTS OF INERTIA AND SECTION MODULI.

The latest volume to be issued in the series of mathematical tables, which is being prepared by the Work Projects Administration for the City of New York under the sponsorship of the Bureau, is entitled "Tables of the Moments of Inertia and Section Moduli of Ordinary Angles, Channels, and Bulb Angles with Certain Plate Combinations." The tables were computed at the suggestion of the Technical Division, Bureau of Marine Inspection and Navigation, Department of Commerce, and should be of value to engineers who use combinations of plates and rolled shapes in the design of structures.

Table I gives moments of inertia and section moduli of ordinary angles, heel-to-plate; Table II gives the same for ordinary angles, toe-to-plate. Table III is concerned with similar data for channels, while Table IV covers bulb angles. Schedules of properties of plates, ordinary angles, channels, and bulb angles occupy 14 pages near the end of the volume.

This book, the serial designation of which is MT-11, contains 210 pages bound in cloth, and sells for $1.25. Orders accompanied by remittances should be sent to the National Bureau of Standards, Washington, D. C.

THE FRANKLIN INSTITUTE

STATED MEETING OF THE INSTITUTE

WEDNESDAY, MAY 20, 1942.

The stated monthly meeting of The Franklin Institute was begun at 8:20 P.M. on Wednesday, May twentieth, by the presiding officer Mr. Charles S. Redding, President.

Mr. John W. Sanstedt, Executive Secretary, National Association of Mutual Savings Banks and member of the National Franklin Committee, played the "Star Spangled Banner," which the audience sang.

Mr. O. T. Anderson, of the American City Bureau in Chicago, and acting in Philadelphia under the auspices of the Chamber of Commerce was then introduced. He spoke briefly regarding the efforts now being put forth by organizations to bring to the attention of the public conditions which will probably exist when the war ends. He outlined the method established to get into touch with the nation as a whole, and explained what was being done to meet the problems which postwar days will bring. He pointed out that, while business and industry will need to be active, the chief responsibility will be in the hands of individual communities. Mr. Anderson ended his talk by lauding Philadelphia for participating wholeheartedly in this highly important project.

The Chairman then announced that this was the regular monthly meeting of The Franklin Institute and called it to order.

He stated that the minutes of the last meeting had been printed in the JOURNAL of the Institute and that, if no objection were offered, they would be approved as printed. They were declared so approved.

The Secretary of the Institute, Dr. Henry Butler Allen, was asked to report. He stated that since the last meeting the following additions in membership have been acquired:

Active	123
Associate	67
Student	36
Total	226

There was no other business. Mr. Redding then continued:

"Three years ago there were held here at The Franklin Institute a series of meetings under the topic, 'Meet Dr. Franklin.' This meeting tonight has been assigned the same topic under the heading: 'Meet Dr. Franklin: A Dynamic Present-Day Force in the American War Effort.'"

He then introduced the first speaker, Mr. William M. Vermilye, Vice-President, National City Bank of New York and Chairman of the National Franklin Committee, which committee was organized by The Franklin Committee within the last year.

Mr. Vermilye presented a resumé of the work of the Committee and told of future plans. He explained that literally thousands of letters to organizations in all fields of endeavor had brought back answers which indicated that the public at large regarded Franklin as a national figure and were interested in the movement to make him better known. Mr. Vermilye's talk was illustrated by slides presenting some of the comments received from educational institutions, national industries, and other groups eager to promote public welfare.

Mr. Redding, in thanking Mr. Vermilye for his paper, stated that the Committee members represented as many as possible of the diversified activities for which Benjamin Franklin stood, and stated that a goodly number of the members were present at this meeting.

The next speaker, Dr. Carl Van Doren, author of the Pulitzer Prize book, "Benjamin Franklin" was then introduced. Dr. Van Doren spoke entertainingly on his researches into Franklin's life and told of bits of information which, coming to him through magazine articles or from letters, rounded out other findings, which would otherwise be incomplete. He expressed appreciation for the many letters and suggestions he has received since his book was published. Dr. Van Doren also gave a list of books on Franklin by other authors which he highly recommended.

At the end of his informal discussion, the Chairman dismissed the meeting with a rising vote of thanks to the two speakers for a very delightful evening.

May 21, 1942.

RESOLUTION CONCERNING THE DEATH OF SIR WILLIAM HENRY BRAGG

At the meeting of the Board of Managers, held Wednesday, March 18, 1942, Dr. Henry Butler Allen, Secretary of The Franklin Institute, announced with regret the death of Sir William Henry Bragg, Director of the Royal Institution of Great Britain, and stated that a cable of sympathy had been sent to the Royal Institution. Sir William was a Franklin Medalist and Honorary Member of the Institute.

Upon motion, the Secretary was authorized to send a suitable Resolution from the Board to the Royal Institution, copy of same to be published in the JOURNAL of the Institute.

In accordance with this action, the following Resolution, prepared by Nathan Hayward, former President of The Franklin Institute, and a personal friend of long standing of Sir William, has been forwarded.

SIR WILLIAM HENRY BRAGG

1862-1942.

Sir William Henry Bragg, honorary member of The Franklin Institute and Franklin Medalist, died on March 13, 1942.

Sir William was born in England in 1862 and received his collegiate education at Trinity College, Cambridge. In 1886 he was appointed Professor of Mathematics at Adelaide, Australia, and while there began his scientific investigations. In 1909 he was appointed Cavendish Professor at Leeds University. In 1923 he was appointed Director of the Royal Institution of Great Britain, which position

he held until his death. He was one of the few men who could possibly have filled this position which was formerly held by Faraday.

To give an idea of his scientific work and recognition, I quote from the citation read when he was given his Franklin Medal:

"Sir William's extensive and valuable studies have been in the modern and important fields of radioactivity, x-rays, and crystal structure; in fact they are of such a fundamental nature that his name is a household word to all students in the exact sciences.

"In radioactivity his experiments on the determination of the ranges of the alpha particles from various radioactive substances throw much light on the mechanics of ionization in gases and on the laws of absorption of these rays by matter.

"In the field of x-rays and crystal structure he showed that the cleavage faces of a crystal reflect x-rays according to the same laws that apply in ordinary optical reflection and he derived the formula known as the Bragg equation for space lattices. Using this equation and with observations made on numerous crystals by means of an x-ray spectrometer of his own design he determined the various distances between the atomic planes in these crystals and the nature of the atoms in these planes. In this way he put crystallography on an exact and measurable foundation." And again in the same citation:

"In 1915 he received the Nobel Prize for physics, which distinction he shared with his son, Professor W. Lawrence Bragg. This is a family achievement of the highest order, without a precedent and with a small mathematical probability coefficient of recurrence in the ages to come."

Sir William's contact with The Franklin Institute was always very close. He first visited us in 1924 at the Centenary Celebration when he read a paper on the carbon atom in crystallized form.

In 1930 he came to the Institute to receive the award of the Franklin Medal, when he gave an address on "The Meaning of the Crystal."

When he came to this country in 1940 to speak before the American Mathematical Society, he did us the honor of spending two days at the Institute.

Howard McClenahan used to say that the Royal Institution and The Franklin Institute were much alike and unique, there being no other institution in the world fulfilling the functions which they perform. This similarity intensified the close interest of Sir William in the Institute. He was most interested in our Christmas lectures which are similar to those which Faraday started at the Royal Institution; and to celebrate their inauguration sent us some of Faraday's apparatus.

We have not the temerity to attempt to analyze the value of the great scientific work of Sir William but we of The Franklin Institute are in a particularly favorable position to pass upon his work as Director of the Royal Institution, and we can say without hesitancy that this is beyond praise.

We of the Institute who were fortunate enough to know him personally will always remember him not only as a great scientist but as a beloved Christian gentleman whose personality made life seem more worth living.

The Franklin Institute records with deep regret the loss of a distinguished member and a valued friend.

CHARLES S. REDDING, *President*
HENRY BUTLER ALLEN, *Secretary.*

COMMITTEE ON SCIENCE AND THE ARTS.

(Abstract of Proceedings of Stated Meeting held Wednesday, May 13, 1942.)

HALL OF THE COMMITTEE,
PHILADELPHIA, MAY 13, 1942.

MR. JOHN B. KLUMPP *in the Chair.*

The following report was presented for final action:

No. 3111: Work of Paul R. Heyl.

This report recommended the award of a Howard N. Potts Medal to Paul Renno Heyl, of Washington, D. C., "In recognition of his numerous contributions to Physical Science with particular reference to the extremely precise measurements which he has made in the field of gravitation."

JOHN FRAZER,
Secretary to Committee.

LIBRARY NOTES.

The Committee on Library desires to add to the collections any technical works that members would wish to contribute. Contributions will be gratefully acknowledged and placed in the library. Duplicates received will be transferred to other libraries as gifts of the donor.

Photostat Service. Photostat prints of any material in the collections can be supplied on request. Orders received in the morning are filled the same day. The average cost for a print 9 × 14 inches is thirty-five cents.

The library and reading room are open daily from nine o'clock A.M. until five o'clock P.M. Saturdays until 12 o'clock noon.

RECENT ADDITIONS.

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NOTES FROM THE BARTOL RESEARCH FOUNDATION.

DIRECTIONAL PROPERTIES OF SELF-QUENCHING COUNTERS.*

BY

W. E. RAMSEY.

H. G. Stever [1] has recently reported a very interesting way in which to endow a Geiger-Mueller counter with directional properties. He finds that small beads of glass mounted on the wire of a counter filled with a self-quenching mixture effectively confines the discharge to those sections of the tube traversed by the original ionizing ray. Thus the pulse size from the wire is proportional to the number of segments traversed and is an indication of the path taken by this ray.

The ability to limit the discharge in self-quenching counters in this way is a consequence of the fact that in these counters not only is the active discharge confined to the immediate vicinity of the wire, as in all counter action, but also to the fact that no photoelectrons are formed in remote parts of the counter as a consequence of photons originating in this region. Emmett L. Hudspeth, using an arrangement employed by the author for studying the distribution of photons in time during the discharge in a non-self-quenching mixture,[2] found this absence of photoelectrons in the case of the self-quenching gas. Thus in the self-quenching mixture the *entire* ionization process is confined to the vicinity of the wire.† Started at a point (or a few points) by the passage of the ionizing ray, it must spread along the wire from this point to another very close to it. It is clear that the discharge may be confined to a desired section of the counter *by any procedure which inter-*

* Reprinted from *The Physical Review*, **61**, 96 (1942).

[1] H. G. Stever, *Phys. Rev.*, **59**, 765 (1941).

[2] W. E. Ramsey, *Phys. Rev.*, **58**, 476 (1940).

† It is essential to adjust the gas mixture until each discharge, as observed on an oscillograph, consists of one single pulse. Failure to break into a continuous discharge with low resistance is not sufficient.

feres with this step-by-step process of propagation at the boundaries of the section.

In one such procedure, and one rich in possible applications, the electric field is reduced at points where it is desired to interrupt the discharge. This has been demonstrated by utilizing the segmented counter employed for other studies.[3,4] Reducing the potential of certain segments (Fig. 1*A*) below the starting potential (say for example 2, 4, 6, 8) we arbitrarily

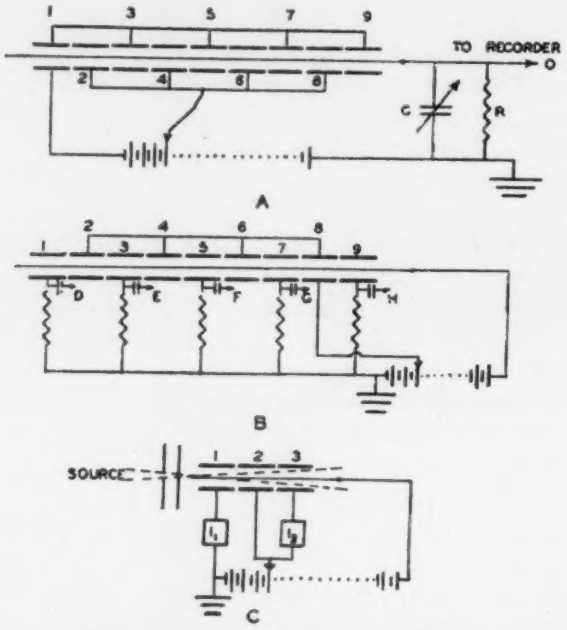

FIG. 1. Counter cylinder composed of separately insulated segments whose potentials may be independently assigned. Filled with a mixture of argon-ether.

divide the counter into a series of lengths (1, 3, 5, 7, 9) which may be used in coincidence in precisely the manner described by Stever. The pulse sizes observed at o are proportional to the number of segments (of the group 1, 3, 5, 7, 9) traversed by the rays passing down the axis of the counter tube. The

[3] W. E. Ramsey, Emmett L. Hudspeth, and Wayne L. Lees, *Phys. Rev.*, **59**, 685 (1941).

[4] W. E. Ramsey, and Wayne L. Lees, *Phys. Rev.*, **60**, 411 (1941).

assignment of active and inactive segments is of course quite arbitrary, and one may divide the same counter into many different coincident groups.

The greatest flexibility is achieved, however, as a result of the fact that voltage pulses (Fig. 1*B*), or charges (Fig. 1*C*) may be taken from the separate segment units. Space does not permit an elucidation of these applications but Figs. 1*B*, 1*C* are suggestive. In 1*B* voltage pulses are taken from the cylinder segments (say *D*, *E*, *F*, *G*, *H*) and applied in any desired manner to the recording circuits. In 1*C* only currents (or total charges) are measured. Here, in segment 1, working in the Geiger counter region, the current to the segment is proportional to the number of ionizing particles which pass through it, while the current to segment 3, working in the proportional region, varies linearly with the product of the number of particles and the specific ionization of the particles involved. Therefore I_3/I_1 is a measure of the specific ionization of the particles of the beam. This procedure, or some obvious modification of it, can provide us with a rugged method for measuring changes of specific ionization of the particles in a beam under conditions where the number of particles does not remain constant. We may thus count particles and simultaneously measure their ionizing capacity *within the same counter.*

NOTES FROM THE BIOCHEMICAL RESEARCH FOUNDATION.

The Effect of Penicillin on the Growth and Morphology of *Staphylococcus Aureus*.—LOUIS DESPAIN SMITH AND THELMA HAY. *Staphylococcus aureus*, used in inhibition tests while determining the rate of production of a bacteriostatic agent by *Penicillium chrysogenum*, was found sometimes to grow sufficiently in low concentrations of the bacteriostatic agent to produce a visible turbidity after eight hours, although the same cultures were without turbidity after 24 hours of incubation. The results of plate counts indicated that there was a definite decrease in viable bacteria during this period of apparent lysis. Gardner (*Nature, 146:* 837, 1940) reported that *Staphylococcus aureus* grown in the presence of penicillin produced by *Penicillium notatum* underwent spherical enlargement and was subject to imperfect fission.

The strains of *Staphylococcus aureus* used, 4776, 6339, 6343, and 6538 of the American Type Culture Collection, were, with the exception of strain 4776, "smooth" strains and produced a uniform turbidity in heart-infusion (Difco) broth. Strain 4776 grew in granular form in fluid media.

The penicillin was obtained from cultures of *Penicillium chrysogenum* grown on whey broth. The method of purification was a modification of that devised by Abraham, et al. (*Lancet*, p. 177, 1941). A detailed account of the production of this bacteriostatic agent by *Penicillium chrysogenum* and the method used for its purification will be published later.

No growth of *Staphylococcus aureus* was found in the higher concentrations of penicillin (greater than 2 micrograms per ml.) even when the inoculum amounted to 2 per cent. of the volume of the broth. In intermediate concentrations (2.0 to 0.2 micrograms per ml.) the growth of the inoculated *Staphylococcus aureus* was approximately as good, for a number of hours, as that in the control tubes without penicillin. After this period of rapid growth, the staphylococci in the tubes containing penicillin stopped growing and underwent partial or

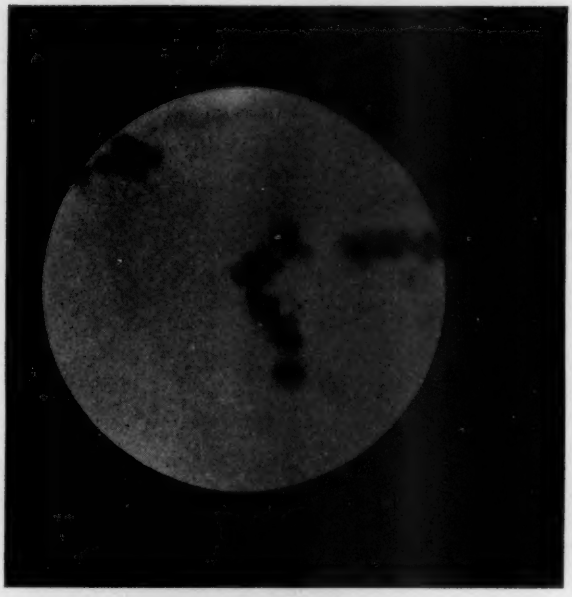

FIG. 1. 24-hour culture of *Staphylococcus aureus* 6343 in heart-infusion broth.

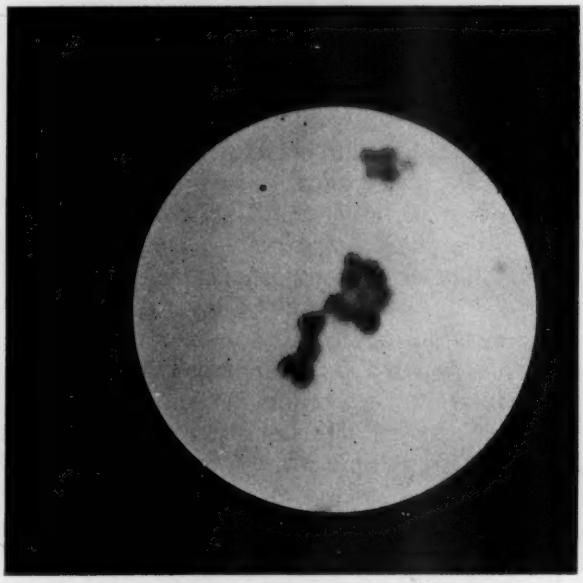

FIG. 2. 3-hour culture of *Staphylococcus aureus* 6343 in heart-infusion broth plus 0.88 microgram penicillin per ml.

complete lysis. The length of time that the inoculum underwent rapid growth was dependent on two factors,—the size of the inoculum and the concentration of penicillin. Within limits, the larger the inoculum used, the longer active growth took place, and the lower the concentration of penicillin, the longer the period before cessation of growth and subsequent partial or complete lysis.

The effect of increasing concentration of penicillin on the period of growth and subsequent lysis is illustrated in Table I.

TABLE I.

Effect of Penicillin on Growth of Staphylococcus Aureus.

Concentration of Penicillin.	Time of Incubation.		
	3 Hours.	7 Hours.	24 Hours.
1.75 micrograms per ml.	20*	0	0
0.88 micrograms per ml.	19	22	11
0.44 micrograms per ml.	25	70.5	66.5
0 micrograms per ml.	30	70.5	88

* Turbidity readings given as percentage of light absorbed.

All four strains of *Staphylococcus aureus* behaved similarly in this regard.

If the period of incubation was allowed to extend over several days, growth usually appeared in concentrations which were inhibitory for 24 hours. In general, subcultures from such tubes contained bacteria which were much more resistant to the inhibitory action of penicillin than were the parent strains. A similar adaptation on the part of *Staphylococcus aureus* to penicillin was reported by Abraham, et al. (*Lancet*, p. 177, 1941).

Photomicrographs 2, 3 and 4 show the increase in size of *Staphylococcus aureus* grown in heart infusion broth containing 0.88 microgram penicillin per ml. These organisms, which were stained with Hucker's gentian violet, show imperfect division which apparently accounts for the larger cell size. In many of these cells, a clear portion across the middle of the cell suggests that only the final step in division is affected and that synthesis of protoplasm is only partially inhibited. Slides made from cultures which had undergone lysis showed

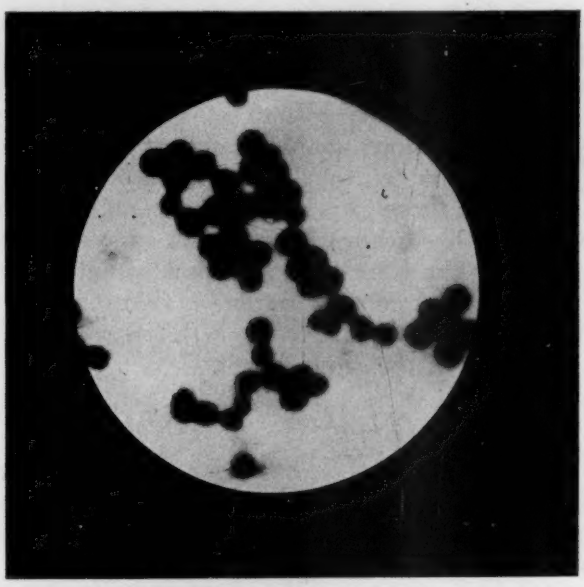

FIG. 3. 5-hour culture of *Staphylococcus aureus* 6343 in heart-infusion broth plus 0.88 microgram penicillin per ml.

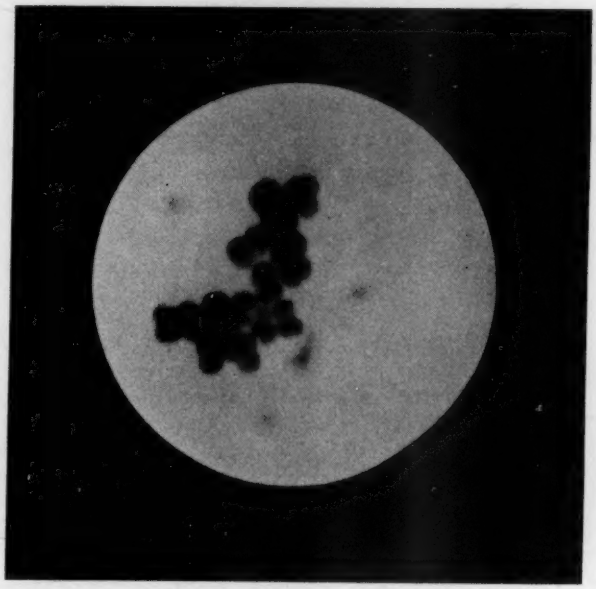

FIG. 4. 24-hour culture of *Staphylococcus aureus* 6343 in heart-infusion broth plus 0.88 microgram penicillin per ml.

small masses of granular material,—evidently the protoplasmic substances released by the breakdown of the cell wall.

These phenomena of swelling and lysis are apparently associated with the active growth of *Staphylococcus aureus*. Fully grown suspensions of this organism showed neither of these effects when added to concentrations of penicillin many times higher than those used in the experiments reported here.

The reason for these phenomena is as yet unknown; it seems possible that penicillin either has some action on the cellular wall of *Staphylococcus aureus* or that it interferes with the assimilation of one or more growth factors necessary for the actual fission of the growing cell.

BOOK REVIEWS.

THE HIGH-SPEED INTERNAL-COMBUSTION ENGINE, by Harry R. Ricardo, F.R.S., Revised by H. S. Glyde, B.Sc. (Eng.) London. 434 pages, illustrations, 18 × 25 cms. New York, Interscience Publishers, Inc., 1941. Price $7.50.

This is the third edition of Volume II of the Internal Combusion engine first published in 1923. Mr. H. S. Glyde, who made this revision, is the assistant of the author and has worked with him for seventeen years. The object of the revision, it is stated, has been to retain as much as possible of the original, the greater part of which dealt with principles of design and fuel behavior, and to supply new subject matter.

The book opens with a treatment on volatile liquid fuel for internal combustion engines. Here the properties of fuels are covered and there are given results of fuel research using a specially designed test engine. The very important subject of detonation is next taken up, discussing the tendency of a fuel to detonate and the factors which influence detonation which leads to the topic of temperatures of the cycle. The role of heat in engine output is a very interesting part as well as the influence of the form of the combustion chamber. Subsequent topics are lubrication and bearing wear, mechanical design and details, valves and valve gear, and piston design. Under the heading of engines for road vehicles, illustrations and descriptions of British engines are given. The likeness to American engines is very striking. High-speed, heavy-duty engines for tanks is a part giving design features for this specialized service. The final chapter is devoted to the latest class of high-speed engine—the Diesel. An outline of the general principles is given.

The book is profusely illustrated with photographs and drawings. The subject is well presented in logical order and should make a very useful text.

R. H. OPPERMANN.

TEMPERATURE MEASUREMENT, by Robert L. Weber. 171 pages, illustrations, 21 × 28 cms. Ann Arbor, Edwards Brothers, Inc., 1941. Price $2.50.

This book is a revision of a preliminary edition published under the title of "A Manual of Heat and Temperature Measurement" (1939). It contains the substance of a course offered for Juniors by the Physics Department of The Pennsylvania State College, requiring as a prerequisite one year of elementary physics.

The first part of the book is devoted to theory. It is divided into fifteen chapters covering generally and in order expansion thermometry, thermoelectric pyrometry, radiation pyrometry and resistance thermometry. The elements of each are discussed with a description of apparatus. Supplementing this there is taken up temperature control, recording pyrometry, colorimetry, thermal analysis, elementary thermodynamics, special methods of temperature measurement, extreme temperatures and a description of the international temperature scale.

Part two contains instructions, for twenty-two experiments which conform and impress the theories in part one. For the most part they are short and

practical. Each has a discussion of sufficient length to cover principles and for orientation. The last part is an appendix containing helpful tables and curves.

The subject is well presented in logical order. The plainness of the explanations and the completeness of coverage, together with the features of being self-contained and comparatively short (some 167 pages), should make this a text and laboratory manual much in demand by engineers as well as instructors.

R. H. OPPERMANN.

MANUFACTURE OF SODA, by Te-Pang Hou, Ph.D. With special reference to the Ammonia Process, a practical treatise, the second edition. 590 pages, illustrations and tables, 16 × 24 cms. New York, Reinhold Publishing Corporation, 1942. Price $9.50.

This is a subject to which there is attached increasing importance. The industry forms one of the most important pillars of the national industrial structure. This can be more easily realized when it is known that soda ash ranks next to sulfuric acid. The acid and the alkali are the two most important basic chemicals a nation possesses, for directly or indirectly, they are used as the raw materials for many other industries.

This second edition of this book has become necessary due to the rapid advances since the first edition. It is similar in construction but contains revisions in almost every chapter. There are five new chapters. The introduction is a historical survey of alkali industry and the relation of Le Blanc soda industry to the development of other chemical industries. Then there follows a discussion on natural soda. A history of the ammonia soda process precedes treatments on preparation and purification of brine, burning of limestone, ammoniation of saturated brine, working of carbonating towers, and the decomposition of sodium bicarbonate by calcination. The recovery of ammonia, the successful accomplishment of which made it possible for the ammonia soda process to compete with the Le Blanc process, is next taken up giving attention to the efficiency of operation in the ammonia still, also by-products and allied products of the industry. Other manufactures associated with the industry mentioned include refined sodium bicarbonate, caustic soda, electrolytic caustic, chlorine and chlorine products. The latter third of the book is devoted to plants involved such as generation of power for ammonia soda plants, control of the process, new developments in the process, behavior of soda ash in storage, layout of the plant, and centrifugal pumps applied to the industry.

The book contains a wealth of material obtained from expert theoretical and practical knowledge of the subject and from published sources. There are many illustrations, tables and curves throughout and a comprehensive subject index in the back. It is a suitable edition to the American Chemical Society Series of Scientific and Technologic Monographs.

R. H. OPPERMANN.

SCIENTISTS FACE THE WORLD OF 1942, by Karl T. Compton, Robert W. Trullinger and Vannevar Bush. Essays, 80 pages, 16 × 24 cms. New Brunswick, Rutgers University Press, 1942. Price $1.25.

This little book contains essays of three foremost men of the day. Dr. Karl T. Compton, president of Massachusetts Institute of Technology, integrates the fundamental sciences of physics, chemistry and biology as they are applied to

engineering at a time when the nation mobilizes its scientific resources for a great defense effort. Dr. Vannevar Bush, biological engineer, discusses the philosophy and the technique of this new field of applied science and demonstrates how fortunate it is that the problems of food, health, and clothing which are acute in times of war have become the subjects of an entire field of scientific inquiry. Dr. Robert W. Trullinger, agricultural engineer, describes how the well-known principles of engineering may be applied to the complex phenomena of the farm provided intelligent deviation from orthodoxy prevails. Commentaries on the three essays are contributed by Harvey N. Davis, Detlev Bronk and S. W. Fletcher.

R. H. OPPERMANN.

THE MANUSCRIPT, A guide for its preparation, 3rd edition, by John Wiley & Sons. 75 pages, illustrations, 15 × 23 cms. New York, John Wiley & Sons, Inc.; London, Chapman and Hall, Limited. 1941. Price $1.00.

Here is a book that undoubtedly has found much use, for since 1924 it is now in its third edition. Yet, the very subject that it covers, suggests that no matter how much use it has had in the past, it can have still greater use in the future. There are always writers and "would be" writers who can profit by having knowledge of the preparation of the manuscript and the handling of proof. Therefore, this book is addressed to everyone.

The first part is devoted to the format of the material and matters of style. Under the former there is discussed the preparation of the copy for the printer, marking type and preparing copy for the offset process. Under the latter can be found such topics as punctuation, numerations, capitalization, spelling, quotations, etc.—everyday topics that everyone needs to brush up on. A very important part is on the preparation of illustrations, something not so generally familiar. Likewise, those items which complete the manuscript are often not so well known. These include the preface, table of contents, appendix and the preparation of the index. With regard to the index, instructions are given which, although of necessity general in nature, if followed should improve published material greatly especially material of a technical nature. A good index often doubles the value of a work.

The second part gives attention to handling the proof—galley proof, page proof, foundry proof and author's alterations. There is an explanation of copy-writing a manuscript and a glossary of terms common in the printing and engraving trades.

R. H. OPPERMANN.

OUTLINES OF FOOD TECHNOLOGY, by Harry W. Loesecke. 505 pages, illustrations, 16 × 24 cms. New York, Reinhold Publishing Corporation, 1942. Price $7.00.

Food is the ever-dominant concern of the human race. The money spent in obtaining food far exceeds that for any other purpose. The number of people gainfully employed in supplying the world with food is greater than in any other occupation. The farmer raises his crops and livestock which he turns over to thousands of others to market. To convert these materials into raw food products, many thousands more are employed in canning, baking, confectionery making, sugar refining, wholesale and storage warehouses, stores, hotels and

restaurants. To this vast army may be added those employed in manufacturing dishes, silverware, machinery for processing foods, bottles, cans, cartons and thousands of other accessories indispensable to the food industry. During our present national emergency, food of course takes on even greater importance.

The objective of the present book is to describe the more important food processes for informative purposes as well as reference. This is done in fifteen divisions, each devoted to a specific subject. The book starts out with the subject of the tin can and the glass container giving the history of food preservation by this means, the composition and construction of the can and glass container, and their washing and cleaning. Subsequently, fruits and their products, and canning of vegetables are taken up. Dairy products, meat and poultry, fish and shellfish, and grains and their products are given consideration from their production, through the various processing stages to the final product. Under edible oils, the character, composition, and preparation of the various oils is discussed. Similar information is given with regard to sugars and starches, nuts, spices, extracts, beverages, jellies and certified dyes. Data given under storage and marketing of fruits and vegetables represent present practice on conditions for storage. The last chapter is devoted to the preservation of foods by freezing.

There is a comprehensive subject index in the back of the book which adds greatly to its value as a reference work. Obviously space limitations prohibit detailed descriptions of the preparation of different food materials. Sufficient coverage is made, however, for the reader to obtain a clear idea of the character of the work. It is surprising how well this is done and the great variety of preparations discussed. At numerous places throughout the work, there are lists of suggested readings for further enlightenment. The construction of the book and method of presentation have strong appeal to those who would use the book for reference.

R. H. OPPERMANN.

THE ELECTRON MICROSCOPE, by E. F. Burton and W. H. Kohl. 233 pages, illustrations, 16 × 24 cms. New York, Reinhold Publishing Corporation, 1942. Price $3.85.

Man has taken measure of atoms and galaxies. Each new instrument developed furthers knowledge of the unknown. New fields have been opened which have revealed untold wonders and unheard of benefits. The electron microscope is such an instrument, for there is convincing evidence that it may be used in a great many research and pioneer studies. Already astonishing results are being obtained. Among the first objects studied were asbestos fibers, diatomaceous earth, clays, carbon black particles, tuberculosis germs, and several viruses. The instrument is many times more powerful than the optical microscope.

This book is a rather complete treatment on the instrument. It endeavors to familiarize the reader with the general principles and outlines the theories that lead to a discussion of electron lenses. The various steps leading to this goal are first a discussion of what constitutes vision, the theory of light microscopes, the nature of light, wave motion, the electromagnetic theory of light, the electron, the dual theories of light and of the electron, electrostatic electron mirrors and lenses, and then the magnetic lens. After this the task is to show how these lenses can be used to produce enlarged images of different types of objects in electron microscopes. Both electrostatic and magnetic electron microscopes are

described, then applications of each are covered. With regard to applications of the former, there is reviewed only investigations on self-emitting objects (cathodes).

Of necessity, the illustrations in a book of this kind, are of extreme importance. There are a great many good photographs throughout the work. The last chapter, on the subject of what the microscope can accomplish, contains photographs of particles in dusts and smokes, photographic emulsions, materials with large complex molecules or molecular aggregates, and biological and medical specimens. The drawings throughout the text are also of much value in driving home the thought presented. The subject matter is well laid out—a carefully chosen and limited introduction to the subject through somewhat familiar channels, an even progression up to the main topic, and a discussion of results to date with possibilities for the future. The book is interesting and impressive. It is valuable to all those who may possibly use the instrument, and as general information for all others.

R. H. OPPERMANN.

EVERYDAY THINGS IN AMERICAN LIFE, 1776–1876, by William Chauncy Langdon. Volume II, 16 × 24 cms., illustrations, New York, Charles Scribner's Sons, 1941. Price $3.00.

During this national emergency, everyday things in American life are brought closer to us. We do not take them so much for granted for we are faced with a shortage and a rationing. Doing without some of these things will mean turning back the pages of time some years to the period before they existed. In some respects we will hark back to the previous generation and realization will be had of what life was without them. This brings to mind how little we realize what life used to be during the first hundred years of our country's existence. True, we all are well aware, more or less, of the history of our country; we know of the progress made in trade, industry and other achievements; our knowledge of our economic status is fair; but few of us ever tried to visualize the life of an average American during this period. This book provides the proper background for such an undertaking.

Being volume two of a set of books, it covers from 1776 to 1876, the Centennial Exhibition. Volume one covered 1607 to 1776, and was mentioned in the JOURNAL of August, 1938. This volume two starts out with what helped more than anything else to develop the country—transportation. A vivid description is given of what the traveller had to put up with during these hundred years, the shipping notices, stage notices, etc., the conditions and comfort of the traveller on the various means of transportation, and even sketching the feelings he had while traveling. His attitude is well portrayed as he experienced the results of progress in the transportation industry.

Everyday things in American life hinged on transportation. The transport of goods improved home life, business was developed, communication improved, and Mr. Citizen had manifold benefits. The book describes the evolution of merchandising, the newspaper, and American cookery. Readers live again the lives of the American of this period. There are descriptions of the home, its equipment, the food that was eaten, and there is a dash of some of the social life of the times. A very interesting illustration is that taken from "Beyond the

Mississippi" by Albert T. Richardson, 1867, showing a cabin on wheels to be drawn by oxen, a bona fide pioneer residence which might be called a fore-runner of the present-day trailer. Clothing, photography, mineral developments and results, machinery, and a great many other subjects are covered. There are many illustrations.

As in the previous volume, the author has done a splendid job. Much of it is dependent on his ability to coördinate the various subjects and weave them into a whole, yet leaving a construction which facilitates reference work. This volume, together with volume one, is interesting, informative, and useful.

R. H. OPPERMANN.

PORTRAITS OF FAMOUS PHYSICISTS, with Biographical Accounts, by Henry Crew. Twelve sections and a Foreword in portfolio form, illustrations, 26 × 35 cms. New York, Scripta Mathematica—Yeshiva College, 1942. Price $3.75.

This portfolio contains portraits of twelve eminent physicists selected by a committee for publication by Scripta Mathematica. There were more than fifty outstanding physicists originally proposed. The committee made no pretension of being able to determine the twelve most eminent physicists of all time, but selected those whom they considered to be genuinely great and whose lives and portraits are of deep interest to all students of physics. Those chosen are Galileo, Huygens, Newton, Ampere, Fresnel, Faraday, Joule, Clausius, Maxwell, Gibbs, Hertz, Rowland.

Henry Crew, a member of the committee, has prepared brief biographical sketches which accompany the portraits. The portraits and biographies furnish an inspiring combination.

R. H. OPPERMANN.

PUBLICATIONS RECEIVED.

Outlines of Food Technology, by Harry W. Loesecke. 505 pages, illustrations, 16 × 24 cms. New York, Reinhold Publishing Corporation, 1942. Price $7.00.

Portraits of Famous Physicists, with Biographical Accounts, by Henry Crew. Twelve sections and a Foreword in portfolio form, illustrations, 26 × 35 cms. New York, Scripta Mathematica—Yeshiva College, 1942. Price $3.75.

Body and Self, One and Inseparable, by Percy A. Campbell. With Mechanical View of Life, Cosmic Rays and Light, Munchausenism in Modern Physics, Twin Mysteries of the Cosmos, etc. 156 pages, 16 × 24 cms. San Francisco, Lawton R. Kennedy, 1942. Price $2.50.

A Short Course in Tensor Analysis, by Gabriel Kron. For Electrical Engineers, 250 pages, 16 × 24 cms. New York, John Wiley & Sons, Inc.; London: Chapman & Hall, Ltd., 1942. Price $4.50.

Volumetric Analysis, by I. M. Kolthoff and V. A. Stenger. Second revised edition, Volume I, 309 pages, illustrations, 16 × 24 cms. New York, Interscience Publishers, Inc., 1942. Price $4.50.

Electric Motors in Industry, by D. R. Shoults and C. J. Rife; edited by T. C. Johnson. 389 pages, illustrations, 16 × 24 cms. New York, John Wiley & Sons, Inc.; London: Chapman & Hall, Ltd., 1942. Price $4.00.

Elements of Heat Transfer and Insulation, by Max Jakob and George A. Hawkins. 169 pages, illustrations, 15 × 24 cms. New York, John Wiley & Sons, Inc.; London: Chapman & Hall, Ltd., 1942. Price $2.50.

CURRENT TOPICS.

A New Chemical Method of Reducing the Reflectance of Glass.—F. H. NICOLL. (*R. C. A. Review*, Vol. VI, No. 3.) The use of an externally applied transparent film on glass, for the purpose of reducing the reflection of light from its surface, has been known for some time. Considerable practical use has been made of evaporated films one-quarter of a wavelength thick. These films have been used to increase the transmission of many optical devices employing lenses, prisms, etc., with very satisfactory results. Many obvious applications of such films have not, however, been realized, due either to lack of hardness of the film or to the high cost of vacuum evaporation. After considerable experimenting a satisfactory arrangement was found for producing uniform films through treatment of glass with hydrofluoric acid vapor. It consisted of a shallow tray two or three inches high with the flat piece of glass to be treated placed over the top, its lower face exposed to the vapor of the acid. The tray itself was supported by blocks about ¼ inch high. Water to a depth of about ½ inch was circulated around and under the tray at a temperature of about 10 degrees below that of the room. A 1 per cent. solution, about 6 to 10 hours (depending on temperature), was required to produce a film of purple color on a piece of ordinary window glass. This film reduced visible reflections to a minimum, about 6 to 10 per cent. of that from untreated glass. Some investigation was made of the effect of concentration and there was evidence that about 5 per cent. HF was the greatest concentration that would produce a suitable hard film without heavy etching. The more concentrated the solution, the more rapid the production of the film. For instance, the vapor from the 48 per cent. HF produced a purple film in about two minutes at room temperature, but the glass was so heavily etched that it became translucent. These films, produced by hydrofluoric acid vapor, were proved to be true interference films of high light transmission by comparing the transmission of glass with and without a film on it.

R. H. O.

Impulse and 60-Cycle Characteristics of Driven Grounds.—P. L. BELLASCHI of Westinghouse Electric and Manufacturing Co. presented a paper on this subject at the A. I. E. E. winter convention in Philadelphia in 1941. Attention was drawn to the fact that the value of protection derived from grounds under actual operating

conditions of lightning discharge was difficult to state in full quantitative measure. This fact led to a preliminary investigation to obtain data on impulse characteristics on actual driven grounds, under impulse currents well approaching lightning conditions. It revealed information relative to the impulse and 60-cycle characteristics of common rods driven in natural soil (largely clay composition) and the ratio of the impulse to the 60-cycle resistance under conditions ranging from a traveling surge to direct strokes. The desirability of establishing the characteristic for other typical soils and for other common types of grounds (electrodes) was apparent. A second paper on the subject was presented at the 1942 A. I. E. E. winter convention in New York. The authors of this paper in addition to Mr. Bellaschi were R. E. Armington and A. E. Snowden. Experimental data are given from tests on twelve additional grounds driven in the field adjacent to the Sharon High Voltage Laboratory. Seven of the grounds were in clay soil in a location which is naturally moist; the resistance of these as shown by a megger was from 10 to 40 ohms. Two of the grounds were in naturally dry and gravelly soil and one was in sand; the megger resistance for these was from 60 to 220 ohms. The remaining two were in soil which consisted of a mixture of clay and stones and meggered from 25 to 190 ohms. The depth of the grounds ranged from 8 to 30 feet. Impulse and sixty cycle data are presented both for the single grounds and for parallel combinations. The impulse data extend up to 15,000 amperes and cover both positive and negative waves as well as other conditions. Analysis of the data shows that the decrease in resistance of driven grounds with increasing impulse current can be considered as the result of an increase in the effective radius and length of the rod. The agreement between experimental curves and curves calculated in this manner establishes the fact that the soil surrounding the rod breaks down at a critical voltage gradient. The two important factors associated with the soil are the resistivity and the breakdown gradient. In addition to providing a basic explanation of the physical processes involved, the analysis indicates that the impulse characteristic curve of a ground may be extrapolated with reasonable assurance to higher currents than the experimental data alone would permit. Furthermore, the methods established may be extended to study the relative characteristics of other types of grounds and arrangements, such as parallel grounds, the footing of tower structures, etc. This paper considers briefly the effect of lead inductance in combination with the ground proper, and it points out the practical importance of the lead or tower structure drop particularly for the rapid current discharge associated with direct strokes. Other factors affecting

the impulse discharge are the conditions in the earth related to the soil and geological structure.

R. H. O.

Wheat Treated with Ethylene Keeps Better and Bakes Better.—Bin-burning of wheat having a high moisture content can be retarded by the use of ethylene gas in the storage bins, research workers of the U. S. Department of Agriculture and the Department of Milling Industry at Kansas State College have found. The gas, at a concentration of approximately one part in 10 thousand of air in the bin was blown into the bin while the damp wheat was being stored. Ethylene gas, which is inexpensive, comes in steel cylinders similar to those used for soda fountain gas. The addition of the gas to air in the bin does not offer serious practical difficulties when bins are reasonably tight. Estimates are that the cost, unless very small quantities are treated, would be a small fraction of a cent per bushel. The ethylene gas used in the tests caused the wheat temperature to remain below 103 degrees for several days, while untreated wheat from the same field and stored at the same time reached 110 degrees and was damaged considerably. Ethylene gas is now widely used in the ripening of citrus fruit and bananas and for loosening walnut hulls, all a result of discoveries by the Bureau of Agricultural Chemistry and Engineering. The ethylene gas treatment, Dr. A. K. Balls and Dr. W. S. Hale of the Bureau point out, is not a "cure-all" treatment that would permit the farmer to harvest his wheat regardless of its stage of maturity. "The treatment," they explained, "will reduce the rate of heating and will permit the farmer or grain handler to store high-moisture wheat for approximately 2 weeks, until it can be dried down to a safe moisture content." In wet harvesting seasons wheat frequently spoils before it can be run through a drier. Wheat that was allowed to mature fully in the field before harvesting was also included in the ethylene storage project. The investigators found that the gas apparently hastened the aging process through which wheat must go after harvesting before it will make flour of satisfactory baking quality. Samples of treated and untreated mature wheats were withdrawn from the storage bins periodically and milled throughout the storage test. The milling was in charge of Dr. E. G. Bayfield, head of the Department of Milling Industry of the College. Significant differences in loaf volumes were observed in favor of the ethylene treated wheat. Apparent improvements in the texture and color of the bread also were noted. Similar experiments are now underway on corn.

R. H. O.

R. C. A. Opens Radiophoto Circuit to Bring Pictures From Australia.—Pictures flashed by radio recently across 7,420 miles of the Pacific from Melbourne to San Francisco when RCA Communications, Inc., opened the first direct radiophoto circuit ever operated between the United States and Australia. This new radiophoto channel to the Antipodes is expected to greatly facilitate the dispatch and exchange of photographs between Australia and America. Arrangements for the service were completed following several days of negotiations and tests by RCAC with the Amalgamated Wireless Company, Ltd., of Australia. Since Australia became the chief focal point of the Pacific war, the demand and the need for direct radiophoto service between the South Pacific and this country has been sharply emphasized. Heretofore, radiophotos originating in Australia have reached the United States through New York by way of London, involving substantially more time and expense in transmission and relay. Normally, photographs measuring 5 × 7 inches are used in transmissions. Reception is at the rate of one inch of the picture every two minutes, so that a photograph scanned across the 5 inch side is received in ten minutes. This radiophoto circuit is the second important communications link established by RCAC between the United States and Australia since this country entered the war. On December 25 a direct radiotelegraph circuit was opened by RCAC between San Francisco and Sydney. Further strengthening of the radio life-line of communication between the United States and Australasia, a new direct RCAC radiotelegraph circuit has been in operation between San Francisco and Wellington, New Zealand, since February 23. That also marked the first direct radio communication to be established between this country and New Zealand.

R. H. O.

Measuring Detonating Forces.—Sensitive instruments developed by the Bureau of Mines to measure the destructive force of air-blasts caused by the detonation of high explosives in mines and quarries are also applicable to the immediate war time problem of damage from demolition bombs and other military explosives, according to Dr. R. R. Sayers, Director of the Bureau. The results of seven years of technical investigations of ground-vibration and air-blast pressure are now available to quarry and mine operators, explosives experts, and military authorities. The latest method of measuring detonating forces originated and tested by the Bureau is a dual channel high-speed cathode ray recording system which, with its delicate instruments, can measure time increments as low as 20

millionths of a second, and can obtain written records at 15,000 inches per second of a blast's advance. This super-sensitive recording system measures the pressure—in pounds per square inch—that is thrown against a building or other object by high explosives at varying distances, and indicates exactly the degree of force necessary to destroy windows and buildings which might be within range of the detonating force. It will also record the amount of air-blast that is reflected, or "bounced," from one building to another following an explosion. Experiments with the Bureau's cathode ray instruments reveal that the main air-blast disturbance caused by the detonation of high explosives is composed of a positive pulse, or outward pressure, lasting a few thousandths of a second, which rises quickly to a maximum and then drops off more slowly. The outward pressure then is followed by a negative pulse, or vacuum, of longer duration which also exerts a force on the building or object within range of the detonation. These facts coincide with descriptions of the behavior of demolition bombs given by experts who have studied this subject under war time conditions in Europe. Because a large number of open quarries and blasting operations are located near residential districts and the problem of property damage is of great concern, the Bureau in 1935 began a study of ground vibrations caused by blasting operations. Early investigations employed microphones placed near arranged shots of explosives, recording of pressure from gas explosions, and the use of crystal elements in the apparatus. Window-glass failure was tested with varying charges of high explosives, and pressure measurements were taken for distances up to 17,000 feet. Development of the highly-specialized recording equipment and the extensive experience acquired by Bureau scientists in the period 1935–1940 provided a background for the cathode ray experiments and the air-blast developments of 1940–1941. By means of the tables and charts compiled in the last two years, users of industrial explosives may limit and control the extent of air-blast damage resulting from detonations in mines and quarries. A given amount of a certain type of high explosive will project its blasting force according to the Bureau's carefully prepared formulas, and this information no doubt will provide increased safety for industrial workers and result in less property damage from broken windows and shattered structures. Methods of recording air-blast damage together with a summary of early experiments and results, are described in Report of Investigations No. 3622 by S. L. Windes, Associate Seismologic Observer.

R. H. O.

War Redirects Efforts of Chemists.—Chemists of the U. S. Department of Agriculture are concentrating their research on new and improved methods of using agricultural raw materials more efficiently in our war effort. Examples of these goals in the Bureau of Agricultural Chemistry and Engineering are: Grease-resistant coatings to use on paper to make it suitable to replace tin cans for packaging food products containing large amounts of lard or vegetable oils, and perhaps even to replace cans as containers for lubricating oils; other coatings for cans and packages for various food products; rubber substitutes and rubber extenders from agricultural commodities available in large quantities such as cornstarch and vegetable oils; vegetable proteins such as the zein of corn studied as a basis for coatings to be used on paper and metal—now regarded as promising since zein is a by-product of cornstarch mills. Plastics and coatings from farm products have gained significance since the war has diverted into explosives most of the carbolic acid that would have gone into phenolic plastics, and into detonators much of the formaldehyde that would have been used in those plastics. Another factor that draws attention to these new plastic materials from farm products is the increasing use for nitrocellulose of cellulose materials that had been going into thermo-plastics. Redirecting the chemists to war research, says DR. HENRY G. KNIGHT, Chief of the Bureau, promises not only to supply needed materials during the emergency but to provide methods and materials likely to prove useful after the war.

R. H. O.

The Gas Turbine.—Dr. J. T. RETTALIATA discusses the development of the gas turbine, thermodynamic considerations, thermal efficiency, and applications in number 7 of Current Trends, one of a series of engineering bulletins published by Allis-Chalmers Manufacturing Company, Milwaukee, Wisconsin. Notwithstanding an ancestry traceable to the time of Hero, the gas turbine has attained commercial significance only comparatively recently. Its successful development is intimately associated with the utilization of elevated temperatures and a highly efficient compressor. Much of the progress realized, therefore, is directly attributable to the efforts of the metallurgist and aerodynamicist. In addition to its application in the oil refinery industry, where it furnishes compressed air to a catalytic cracking process for the production of high octane gasoline, the combustion gas turbine is also being employed in the generation of electric power, as well as for locomotive drives. A recapitulation of the material presented indicated that the future of the

gas turbine becomes more promising with the adoption of higher temperatures. Continued metallurgical advances and effective cooling methods bring operation at elevated temperatures ever closer to the realm of practicability. Field experience with the units already in operation indicates their design to be conservative, and no troubles attributable to operating temperatures have been encountered. Based upon this experience, as well as that of supercharger work, it is believed that operation at temperatures higher than those now in use is entirely feasible and that it can be accomplished with an adequate margin of safety. Improvement in thermal efficiency, made possible by the use of regeneration and increased temperature, makes the gas turbine a serious aspirant as a prime mover for certain applications. Because of the low grade of fuel it can use, the gas turbine even when operating at present temperature levels without regeneration compares favorably on a fuel cost basis with other methods of power production. Undoubtedly the gas turbine has certain natural applications which make the cycle appear attractive. The advantages associated with the elimination of the high pressure, high temperature steam boilers, and the attendant feedwater problems from a power plant are obvious. At present the cycle is only applicable where liquid or gaseous fuels can be used although research has shown some promise for the application of pulverized fuel for this service. The gas turbine is not regarded as the answer to all power problems since its limitations are well recognized. It is believed, however, that it possesses definite features which ideally adapt it for certain classes of service; and it is toward this end that the present development is being directed.

R. H. O.

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